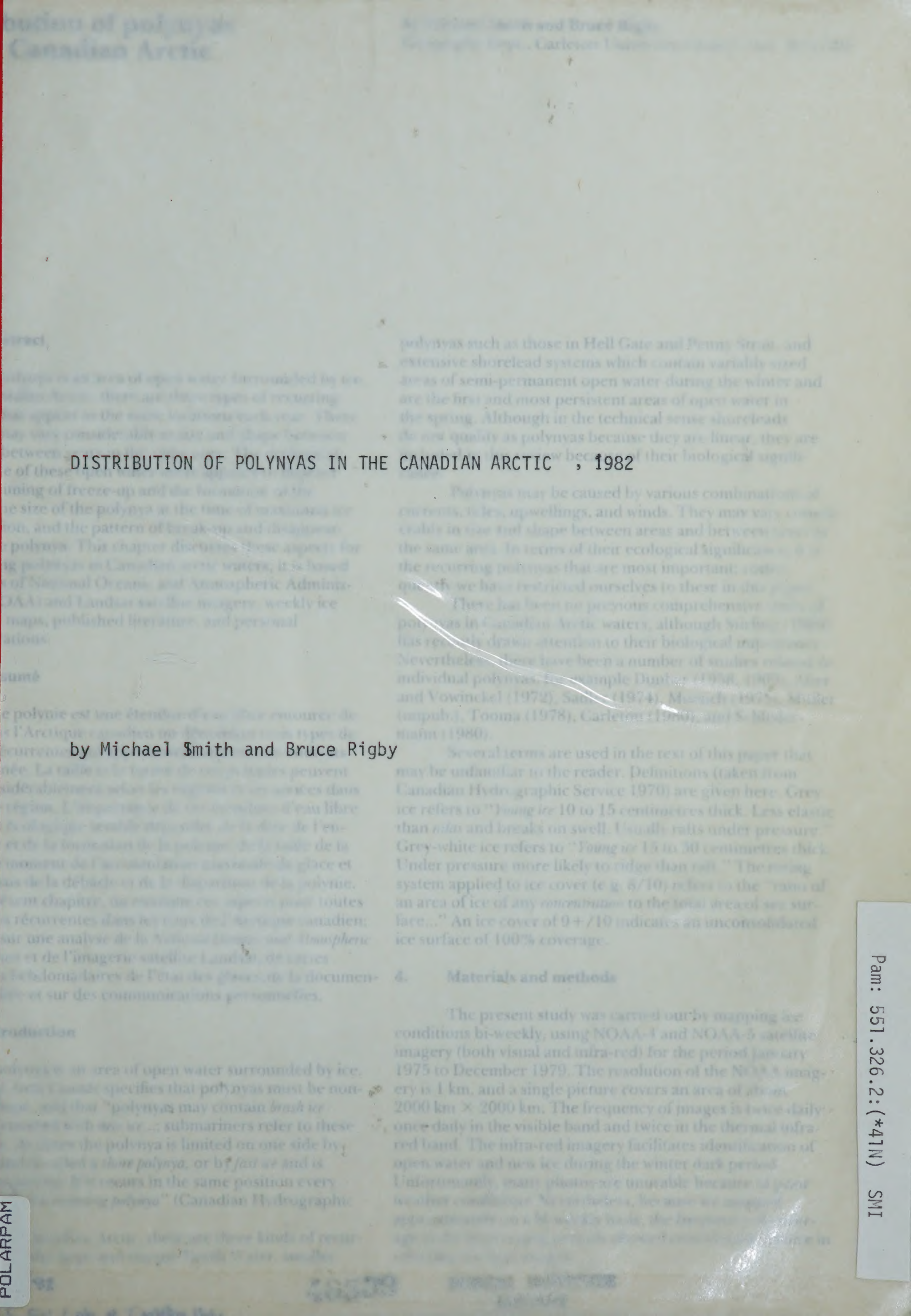


# DISTRIBUTION OF POLYNYAS IN THE CANADIAN ARCTIC , 1982

by Michael Smith and Bruce Rigby

POLAR
PAM
2053

POLARPAM

Pam: 551.326.2:(*41N) SMI

# Distribution of polynyas in the Canadian Arctic

by **Michael Smith and Bruce Rigby**
Geography Dept., Carleton University, Ottawa, Ont. K1S 5B6

## 1. Abstract

A polynya is an area of open water surrounded by ice. In the Canadian Arctic, there are three types of recurring polynyas that appear in the same locations each year. These polynyas may vary considerably in size and shape between areas and between years in the same area. The ecological importance of these open water areas appears to depend upon the timing of freeze-up and the formation of the polynya, the size of the polynya at the time of maximum ice accumulation, and the pattern of break-up and disappearance of the polynya. This chapter discusses these aspects for all recurring polynyas in Canadian arctic waters; it is based on analysis of National Oceanic and Atmospheric Administration (NOAA) and Landsat satellite imagery, weekly ice composite maps, published literature, and personal communications.

## 2. Résumé

Une polynie est une étendue d'eau libre entourée de glace. Dans l'Arctique canadien on dénombre trois types de polynies récurrentes qui apparaissent aux mêmes endroits chaque année. La taille et la forme de ces polynies peuvent varier considérablement selon les régions et les années dans une même région. L'importance de ces étendues d'eau libre sur le plan écologique semble dépendre de la date de l'englacement et de la formation de la polynie, de la taille de la polynie au moment de l'accumulation maximale de glace et du processus de la débâcle et de la disparition de la polynie. Dans le présent chapitre, on examine ces aspects pour toutes les polynies récurrentes dans les eaux de l'Arctique canadien; il est basé sur une analyse de la *National Oceanic and Atmospheric Administration* et de l'imagerie satellite Landsat, de cartes composites hebdomadaires de l'état des glaces, de la documentation publiée et sur des communications personnelles.

## 3. Introduction

A polynya is an area of open water surrounded by ice. The *Pilot of Arctic Canada* specifies that polynyas must be non-linear in shape, and that "polynyas may contain *brash ice* and/or be covered with *new ice*...; submariners refer to these as skylights. At times the polynya is limited on one side by the coast, and is called a *shore polynya,* or by *fast ice* and is called a *flaw polynya.* If it recurs in the same position every year, it is called a *recurring polynya*" (Canadian Hydrographic Service 1970).

In the Canadian Arctic, there are three kinds of recurring polynyas: the large and unique North Water, smaller polynyas such as those in Hell Gate and Penny Strait, and extensive shorelead systems which contain variably sized areas of semi-permanent open water during the winter and are the first and most persistent areas of open water in the spring. Although in the technical sense shoreleads do not qualify as polynyas because they are linear, they are included in this review because of their biological significance.

Polynyas may be caused by various combinations of currents, tides, upwellings, and winds. They may vary considerably in size and shape between areas and between years in the same area. In terms of their ecological significance, it is the recurring polynyas that are most important; consequently we have restricted ourselves to these in this paper.

There has been no previous comprehensive study of polynyas in Canadian Arctic waters, although Stirling (1980) has recently drawn attention to their biological importance. Nevertheless, there have been a number of studies related to individual polynyas, for example Dunbar (1958, 1969), Aber and Vowinckel (1972), Sadler (1974), Muench (1975), Müller (unpub.), Tooma (1978), Carleton (1980), and Schledermann (1980).

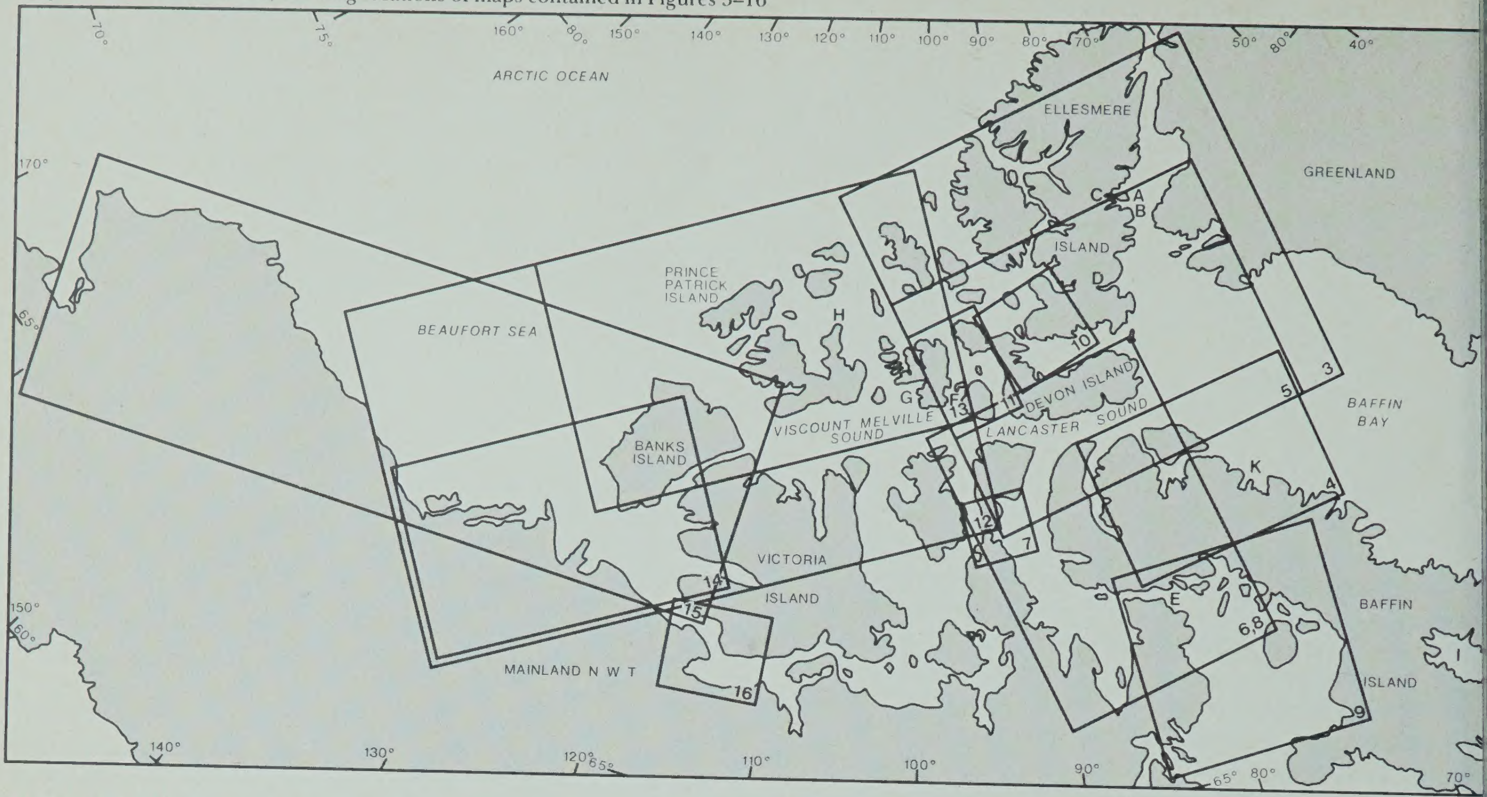
Several terms are used in the text of this paper that may be unfamiliar to the reader. Definitions (taken from Canadian Hydrographic Service 1970) are given here. Grey ice refers to "*Young ice* 10 to 15 centimetres thick. Less elastic than *nilas* and breaks on swell. Usually rafts under pressure." Grey-white ice refers to "*Young ice* 15 to 30 centimetres thick. Under pressure more likely to ridge than raft." The rating system applied to ice cover (e.g. 8/10) refers to the "ratio of an area of ice of any *concentration* to the total area of sea surface..." An ice cover of 9+/10 indicates an unconsolidated ice surface of 100% coverage.

## 4. Materials and methods

The present study was carried out by mapping ice conditions bi-weekly, using NOAA-4 and NOAA-5 satellite imagery (both visual and infra-red) for the period January 1975 to December 1979. The resolution of the NOAA imagery is 1 km, and a single picture covers an area of about 2000 km × 2000 km. The frequency of images is twice daily: once daily in the visible band and twice in the thermal infrared band. The infra-red imagery facilitates identification of open water and new ice during the winter dark period. Unfortunately, many photos are unusable because of poor weather conditions. Nevertheless, because we mapped approximately on a bi-weekly basis, the frequency of coverage in the intervening periods allowed considerable choice in selecting the best images.

'd:
der No.: Feb 22/82
ce: Free
No.: Geotech Sci Lab at Carleton Univ.
46539
BOREAL INSTITUTE
LIBRARY

**Figure 1**
Map of the Canadian Arctic, showing locations of maps contained in Figures 3–16



Polynyas covered by this paper
(numbers refer to figures in text)
**3** North Water
**3** Coburg Island
**4** Bylot Island
**5** Lancaster Sound
**6** Prince Regent Inlet
**7** Bellot Strait
**8** Committee Bay
**9** Foxe Basin
**10** Hell Gate – Cardigan Strait
**11** Queens Channel – Penny Strait
**12** Arctic Ocean lead system
**13** Prince Patrick Island
**14** Cape Bathurst
**15** West of Cape Bathurst
**16** Lambert Channel
Franklin Strait

Polynyas not covered by this paper
**A** Camperdown Polynya
**B** Rice Strait
**C** Hazler Bay
**D** Mackinson Inlet
**E** Fury and Hecla Strait
**F** Kailuk Brooman
**G** Alexander Polynya
**H** Melville Island
**I** Cumberland Sound
**J** Frobisher Bay
**K** Cambridge Fjord

Landsat imagery, which has been available since 1972, was also used, but only to a limited degree. Landsat has a higher resolution (80 m) than NOAA; however, each image covers an area of only 185 × 185 km with considerable overlap between images. For example, it can take up to nine separate photographs to cover the small polynya in Bellot Strait. The frequency of Landsat is only once every 18 days. Thus, both the smaller scale and more frequent coverage made the NOAA imagery more suitable for this survey study. Similarly, Dey *et al.* (1979) used the NOAA imagery for a study of freeze-up and break-up patterns in the Canadian Arctic for the period July to November, 1975–77. In contrast, Landsat would probably be better for detailed studies of individual polynyas.

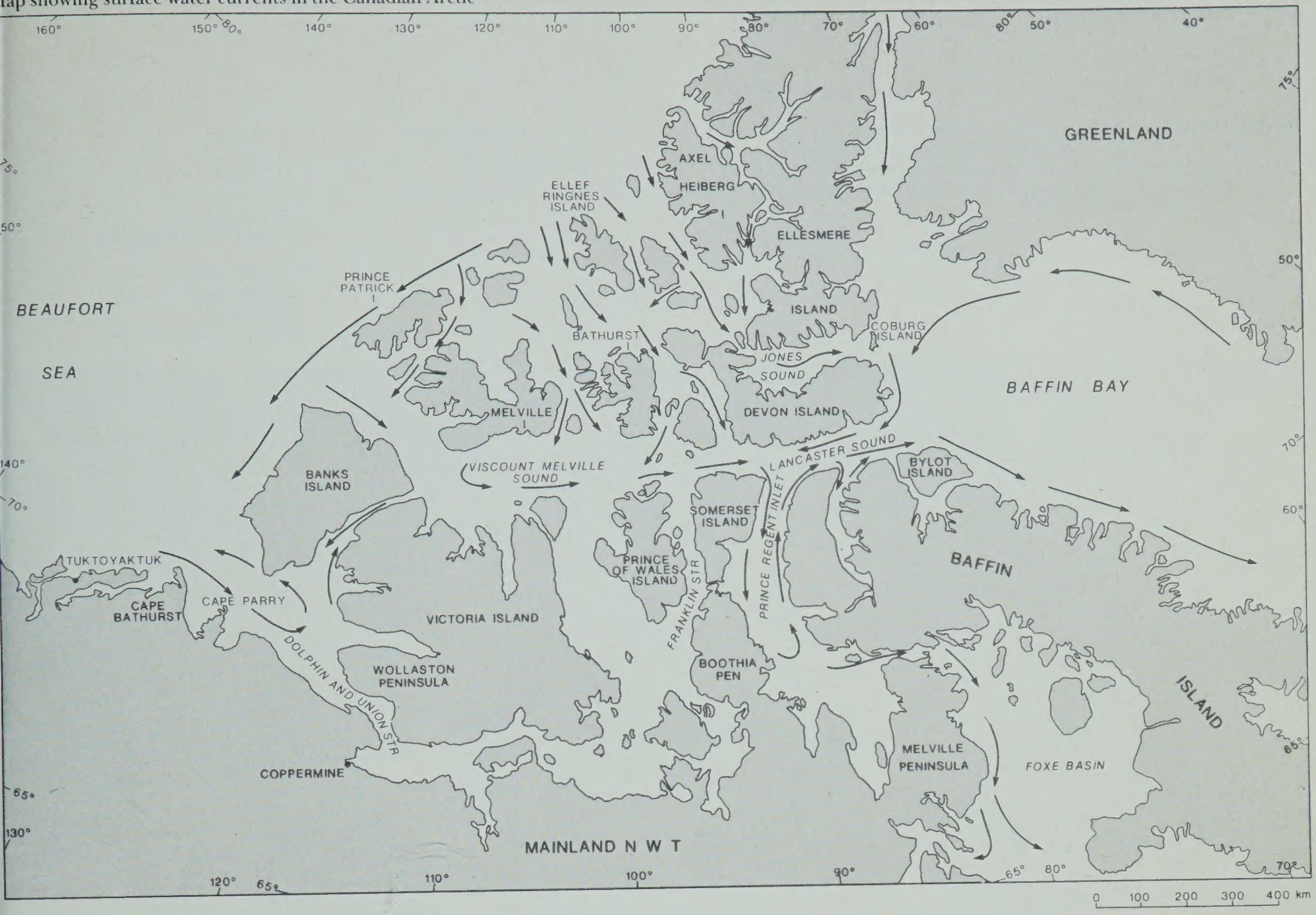
In addition to the NOAA imagery, weekly ice composite maps from the Ice Climatology and Applications Division (Atmospheric Environment Service) were also used. These composites were compiled from NOAA imagery, ice reconnaissance flights, laser profilometry, and various other ice observations, but cover only the duration of the northern shipping season (generally May to November). Finally, information was also obtained from published literature and personal communications.

The polynyas analysed in this study are illustrated collectively by Stirling (this publication, Fig. 1). For this paper, it was necessary to consider individual areas of the Arctic separately on a larger scale as shown in Figure 1. In addition, a number of smaller existing features are also indicated although they were not analysed here. Because of their importance to the location and recurrent nature of many polynyas, the major arctic marine current systems are shown in Figure 2.

The study period was limited to the last 5 years, primarily because, prior to 1975, the quality of the NOAA imagery was much poorer. This made interpretation more difficult and less reliable. The AES composite maps were also available from 1975 through 1979 so that we were able to verify our interpretations. Even so, some errors in the interpretations could have occurred due to the interpreter, or because of aberrations introduced by photo quality, cloud cover, and fog banks. In addition, because newly-formed thin ice is difficult to distinguish from open water in both the visual and infra-red bands, all dark areas were simply mapped as open water. Some small features, such as the polynya in Fury and Hecla Strait, were detectable on the photos but were very difficult to map accurately.

Because of the limitations of the imagery, and our conservative interpretation, only the main characteristics of the larger recurring polynyas were mapped in this study. In analysing the data, we concentrated on the aspects that seemed to be most important ecologically. These included
(1) the timing of freeze-up and the formation of the polynya,
(2) the size of the polynya at the time of maximum ice accumulation, and
(3) the pattern of break-up and disappearance of the polynya and its eventual connection to other water bodies.
In each instance we have tried to indicate what is "normal" as well as the range of variation over the 5-year period.

igure 2
ap showing surface water currents in the Canadian Arctic



## 5. Locations and variability of polynyas

### 5.1. The North Water

The North Water, situated in northern Baffin Bay, is the largest and best known polynya in the Canadian Arctic. During the early winter, pack ice being carried south through Kane Basin becomes congested and forms an ice bridge across the narrow head of Smith Sound. New ice that is formed south of the bridge is apparently swept away by the current, aided by the prevailing northerly winds (Nutt 1969) although some have suggested that the upwelling of water is important. Because of the ice bridge, the northern limit of the North Water is fairly constant from year to year; however, the southern edge is more variable and depends on weather conditions and the time of year. A number of papers have been written on various aspects of the North Water (e.g. Dunbar 1969; Aber and Vowinckel 1972; Muench 1975; Tooma 1978; Müller, unpubl.).

Freeze-up in Smith Sound usually begins in mid September (except in 1979, when it occurred during mid to late August), commencing in the northwest and growing southwards. The eastern and western waters of Kane Basin freeze fast to the shore at this time, although a central "corridor" of mobile ice (some new, some 1-year-old, and some multiyear) persists until December or January when the ice bridge begins to form. The ice bridge and open water area at the head of Smith Sound formed in mid January in 1975, 1977, and 1979, in February in 1976, and in mid March in 1978.

By late October, northern Baffin Bay is covered with ice, most of which is less than 1 year old. An extremely constant fast-ice edge develops along the eastern coasts of Ellesmere and Devon islands to Lancaster Sound, and along the northwestern coast of Greenland to Northumberland Island (Fig. 3*a*). Some open water is always present along the Ellesmere and/or Greenland coasts, with an especially consistent patch just southwest of Coburg Island (see section 5.2). Very often there is also open water around Northumberland Island and in Melville Bay. In 2 of the past 5 years (1975, 1976) there has been open water in northernmost Nares Strait in January and February (Fig. 3*a*).

The northernmost area of Baffin Bay south of the ice bridge remains in a disturbed state throughout the winter. Currents, winds, and the counterclockwise gyre in the main part of Baffin Bay keep the ice in constant motion. During winter this area always shows as quite dark on the NOAA infra-red imagery (Fig. 3*b–d*), indicating thin ice that may contain partly or completely open areas.

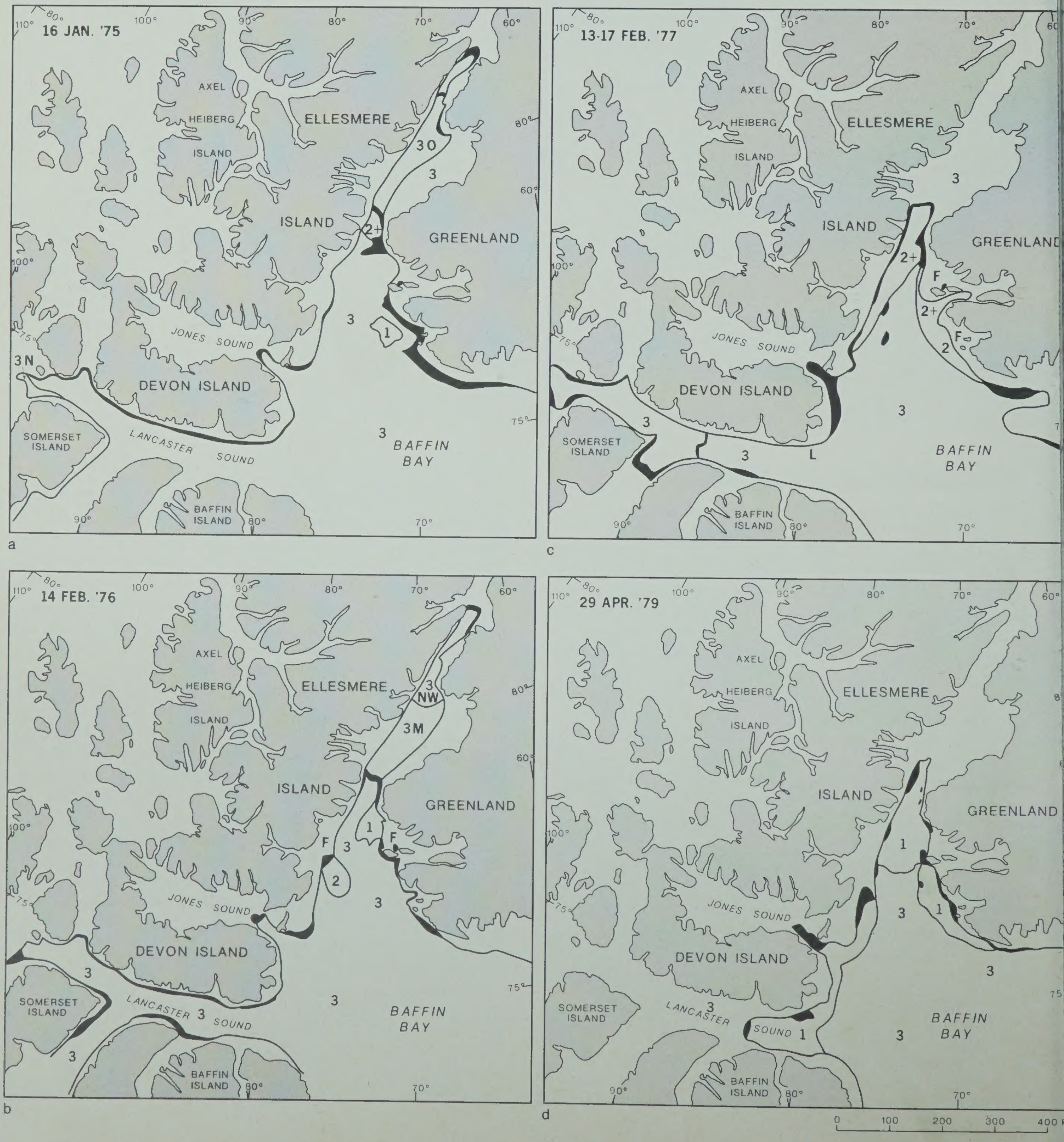
Persistent open (or semi-open) water exists in confined areas at the northern end of Smith Sound, at the entrance to Jones Sound off Coburg Island, in Lancaster Sound off the southeastern coast of Devon Island, and around Northumberland Island (Fig. 3*e*). The main area of open water begins to expand southwards in northern Baffin Bay in the first half of May (Fig. 3*f*) (early to mid April in 1977, late April in 1979). The spread of the polynya southwards proceeds somewhat differently in detail from year to year, but typically by the end of May the southern edge is around 76°N ± ½° (Fig. 3*g, h*). The southern extent of the open water is greater down the western side of Baffin Bay. Nevertheless, the North Water does not normally join Lan-

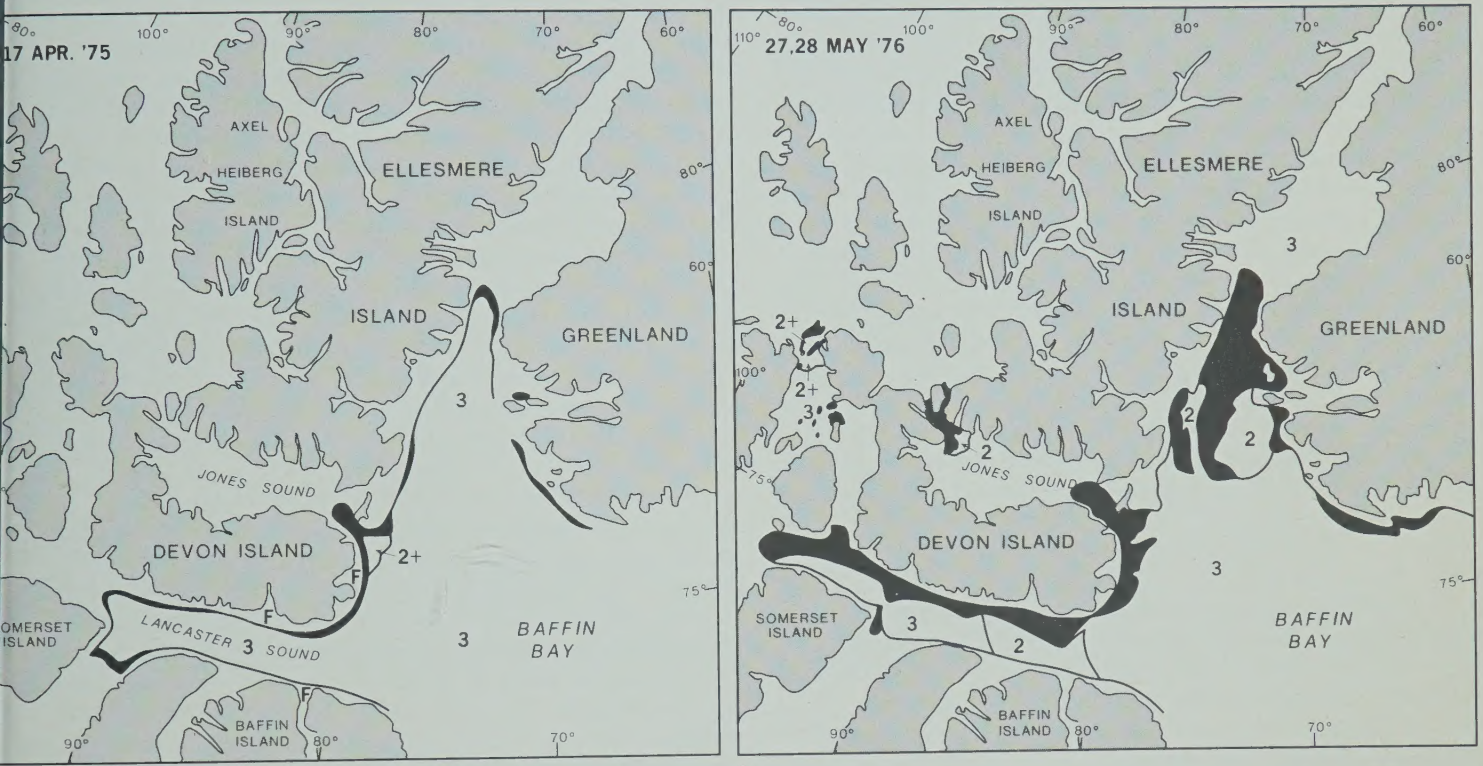
**Figures 3a–h**
Maps of the North Water polynya, showing ice conditions during particular months and years as indicated

▬ large black areas indicate open water to 1/10 ice cover
thin line leading into thicker line indicates a crack/lead
——— single thin line indicates division between ice cover categories
L indicates an open lead and is inserted in some cases where the lead is not obvious

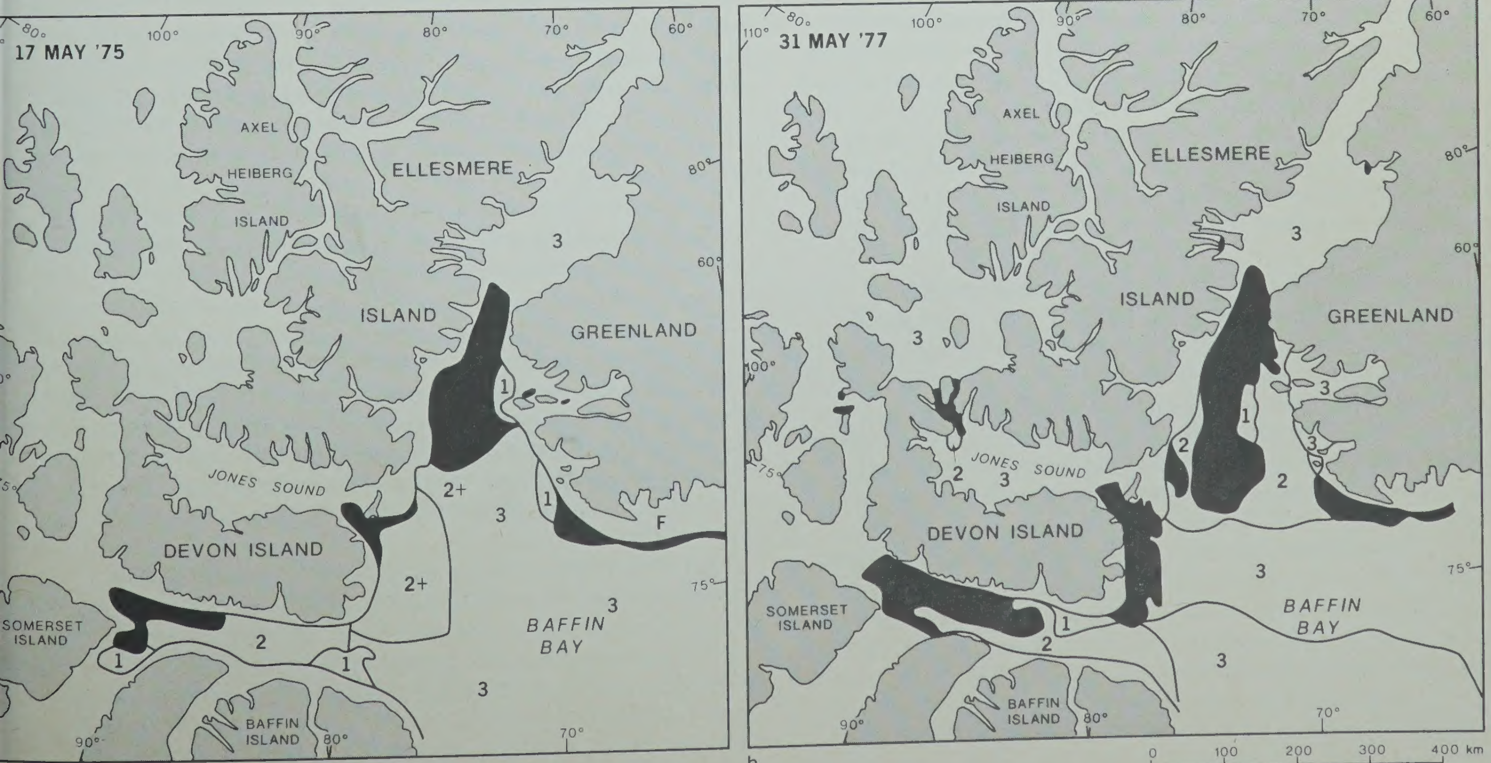
| | |
|---|---|
| **1** | 2/10 – 5/10 ice cover |
| **2** | 6/10 – 7/10 ice cover |
| **2+** | 8/10 ice cover |
| **3** | 9/10 – 10/10 ice cover |

| | |
|---|---|
| **F** | fast ice |
| **N** | new ice |
| **O** | old ice |
| **M** | multiyear ice |
| **A** | 1st-year ice |
| **<A** | less than 1st-year ice |
| **S** | 2nd-year ice |
| **U** | unknown |
| **G** | grey ice |
| **W** | grey-white ice |




17 APR. '75
AXEL HEIBERG ISLAND
ELLESMERE ISLAND
GREENLAND
JONES SOUND
DEVON ISLAND
OMERSET ISLAND
LANCASTER 3 SOUND
BAFFIN BAY
BAFFIN ISLAND
2+
F
3
100°
90°
80°
70°
60°
75°
27,28 MAY '76
AXEL HEIBERG ISLAND
ELLESMERE ISLAND
GREENLAND
JONES SOUND
DEVON ISLAND
SOMERSET ISLAND
BAFFIN BAY
BAFFIN ISLAND
2+
3
2
110°
100°
90°
80°
70°
60°
75°

g


17 MAY '75
AXEL HEIBERG ISLAND
ELLESMERE ISLAND
GREENLAND
JONES SOUND
DEVON ISLAND
SOMERSET ISLAND
BAFFIN BAY
BAFFIN ISLAND
1
2
2+
3
F
100°
90°
80°
70°
60°
75°
31 MAY '77
AXEL HEIBERG ISLAND
ELLESMERE ISLAND
GREENLAND
JONES SOUND
DEVON ISLAND
SOMERSET ISLAND
BAFFIN BAY
BAFFIN ISLAND
1
2
3
110°
100°
90°
80°
70°
60°
75°
0
100
200
300
400 km

h

caster Sound until mid June (late May in 1979). Sometime in July the North Water merges with the open water spreading northwest from Davis Strait, although in 1978 this did not occur until September.

The ice bridge in Smith Sound breaks up in late July (1979) or early August (1975–78 inclusive), at which time open water can extend north into Nares Strait.

### 5.2. Coburg Island

An especially persistent area of open water occurs during the winter every year in the vicinity of Coburg Island. This polynya remains as a separate feature for some months before joining the main body of the North Water in May or June.

Freeze-up occurs in late September or early October, beginning in Jones Sound and encompassing Coburg Island by mid to late October. Annual ice prevails in this region. Open water first appears in January (except December 1978), typically in the form of a horseshoe-shaped lead in Lady Ann Strait, southwest of Coburg Island (Fig. 3*a*). The lead develops at the boundary between the fast ice in Jones Sound and the pack ice of Baffin Bay. However, the open water is so regular in form and location from year to year that it may be related to the southeastern current from Jones Sound, which is channelled through the strait (Fig. 2).

Open water remains here all winter and can become quite extensive (e.g. Fig. 3*c–f*). Leads may extend to the North Water or south towards Lancaster Sound, usually connecting to the latter by April. The North Water extends south past Coburg Island from mid May to early June (mid July in 1978), although prior to this period it may be connected intermittently via the shorelead along the Ellesmere coast.

### 5.3. Bylot Island

In all 5 years, an area of open water was observed parallel to the eastern or southeastern coast of Bylot Island (Fig. 4*a*). It is a rather difficult feature to map because of the frequent heavy cloud in this region. Although this open water area eventually joins up with the North Water, initially it develops as a separate feature.

The waters around Bylot Island are usually frozen by the end of October, accompanying the freeze-up of Baffin Bay. A lead develops between the shorefast ice around Bylot Island and the drift ice in Baffin Bay; the opening and closing of the lead is related to winds and the general motion of the pack ice in Baffin Bay. The feature varies somewhat in size and specific location from year to year, but is always located along the eastern coast of the island, extending south across the entrance to Pond Inlet and past Cape Macculloch on Baffin Island.

From 1976 to 1979, the Bylot Island lead first appeared in February, while in 1975 the opening was first noted in March. In 1977, 1978, and 1979, it consisted of an open lead off the southeastern coast of Bylot Island, extending southwards past Cape Jameson, Baffin Island (e.g. Fig. 4*a*). In 1976 it also extended around the northern coast of Bylot Island (Fig. 4*b*). In 1975 the lead was quite wide and closer inshore, and ran south along the east coast of Bylot Island to Cape Macculloch (Fig. 4*c*).

The opening usually disappears by April, as it did in 1976, 1977, and 1978. In 1975, it disappeared in early May. In 1979, the opening became confined to a small open water area off the southeastern corner of the island, and in 1976 this same small opening reappeared in May (Fig. 4*d*).

As previously stated, this polynya eventually merges with the North Water when break-up occurs in Baffin Bay. This linkage can occur as early as June (as in 1975) or as late as August (as in 1977).

### 5.4. Lancaster Sound

Landfast ice forms by late September or early October in Lancaster Sound. By mid to late October the sound usually becomes completely ice-covered, although still unconsolidated (9+/10). A system of open shoreleads and cracks usually develops between mid November (1975, 1976) and mid December (1974, 1977), remaining in some form throughout the winter until break-up. It was absent in winter 1978–79, however, as ice in Lancaster Sound became consolidated. The lead system runs along the northern and southern sides of Lancaster Sound, extending south into Prince Regent Inlet where it may be open south of Creswell Bay on the western side (e.g. Fig. 5*a*). The pattern of leads changes periodically under the influence of currents and winds. Included in this system is a lead which begins near the western end of Lancaster Sound and may extend as far west as Griffith Island and Lowther Island, as it did in January and February of 1975, 1976, 1977, and 1978 (Fig. 5*a*). In 1976, the lead remained in this position throughout the winter (Fig. 5*b*) until break-up in late May. In 1975 and 1977, the lead around Lowther Island froze over in about early February and late March respectively. At about this time, another lead develops in the vicinity of Prince Leopold Island, and runs north toward Maxwell Bay and then east along the south coast of Devon Island (Fig. 5*c*, *d*). Historically, the location of this opening has been remarkably constant (Smiley and Milne 1979) and may be related to the submarine sill in Lancaster Sound at this point.

In 1978, the lead at Prince Leopold Island first appeared around March 11 but had refrozen by March 25. At this time, open water was restricted to a lead running between Cape Sherard (Devon Island) and Navy Board Inlet. In 1979, the only open water in Lancaster Sound was contained in a transverse lead running north–south near the entrance to the sound (Fig. 5*e*). The lead developed by early January and joined with the North Water in the second half of May.

During the winter, the lead along the northern side of Lancaster Sound may be continuous throughout its whole length and can link with the polynya near Coburg Island, depending on wind conditions and the movement of ice in Baffin Bay (Fig. 5*a*, *c*). At other times the lead is discontinuous (Fig. 5*b*). On the southern side of Lancaster Sound, the lead is not usually continuous as far east as the polynya off Bylot Island.

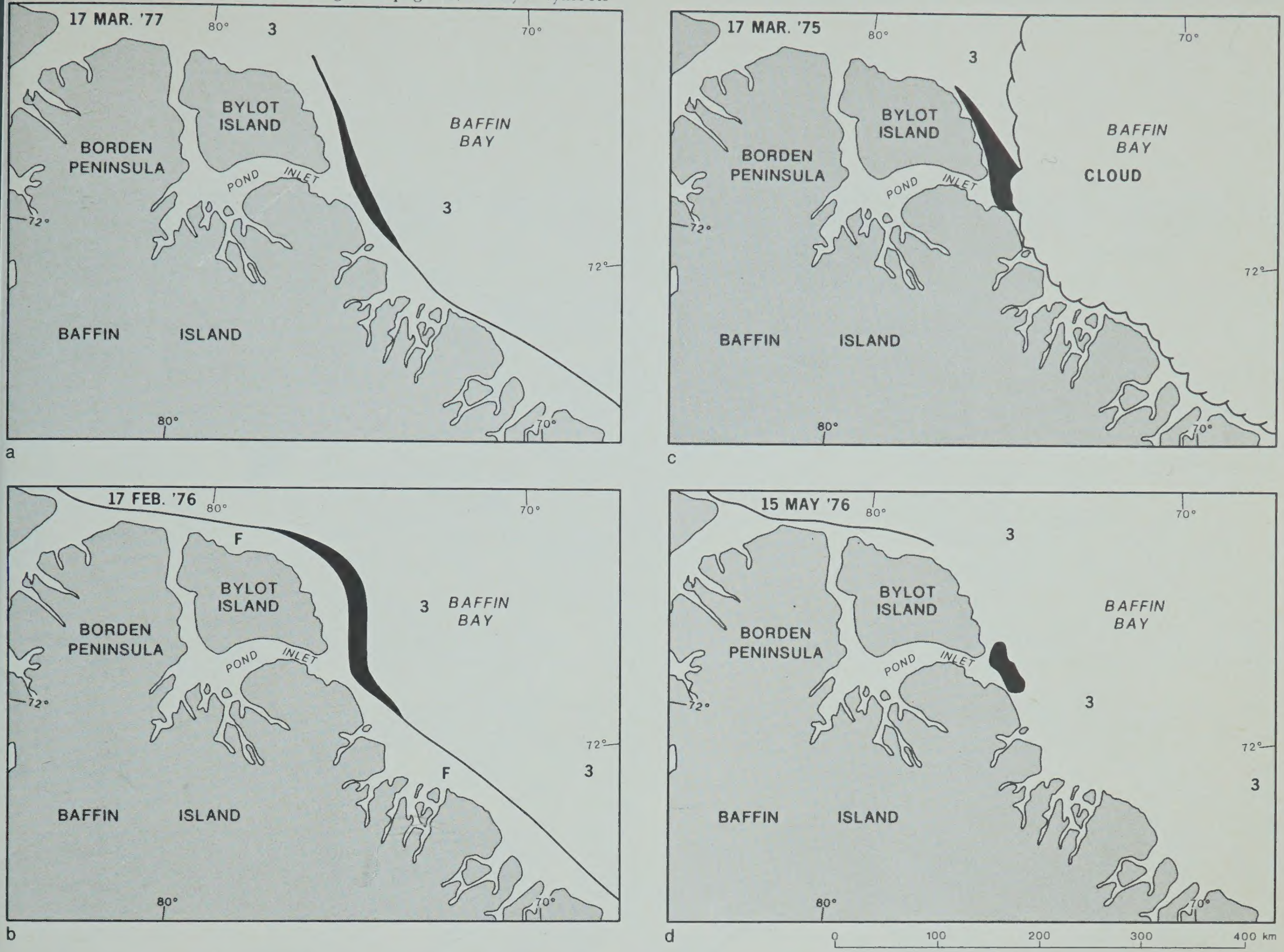
Break-up commenced in early to mid May in 1975 and 1977 and late May in 1976. In 1978 and 1979, break-up did not occur until sometime in August.

### 5.5. Prince Regent Inlet

Freeze-up usually occurs in Prince Regent Inlet and the Gulf of Boothia no later than mid October. Since Prince Regent Inlet only becomes ice free as far south as a line between Lord Mayor Bay, Boothia Peninsula, and Crown Prince Frederick Island, there is a division between the annual ice in Prince Regent Inlet and multiyear ice in the Gulf of Boothia.

In January, a characteristic pattern of cracks and shoreleads develops along both the east and west sides of Prince Regent Inlet, south into the Gulf of Boothia and Committee Bay (Fig. 6*a*). This lead system also joins with leads along the southern side of Lancaster Sound. The pattern is very similar to the pattern of currents in this region (Fig. 2). An open lead commonly occurs along the eastern and north-

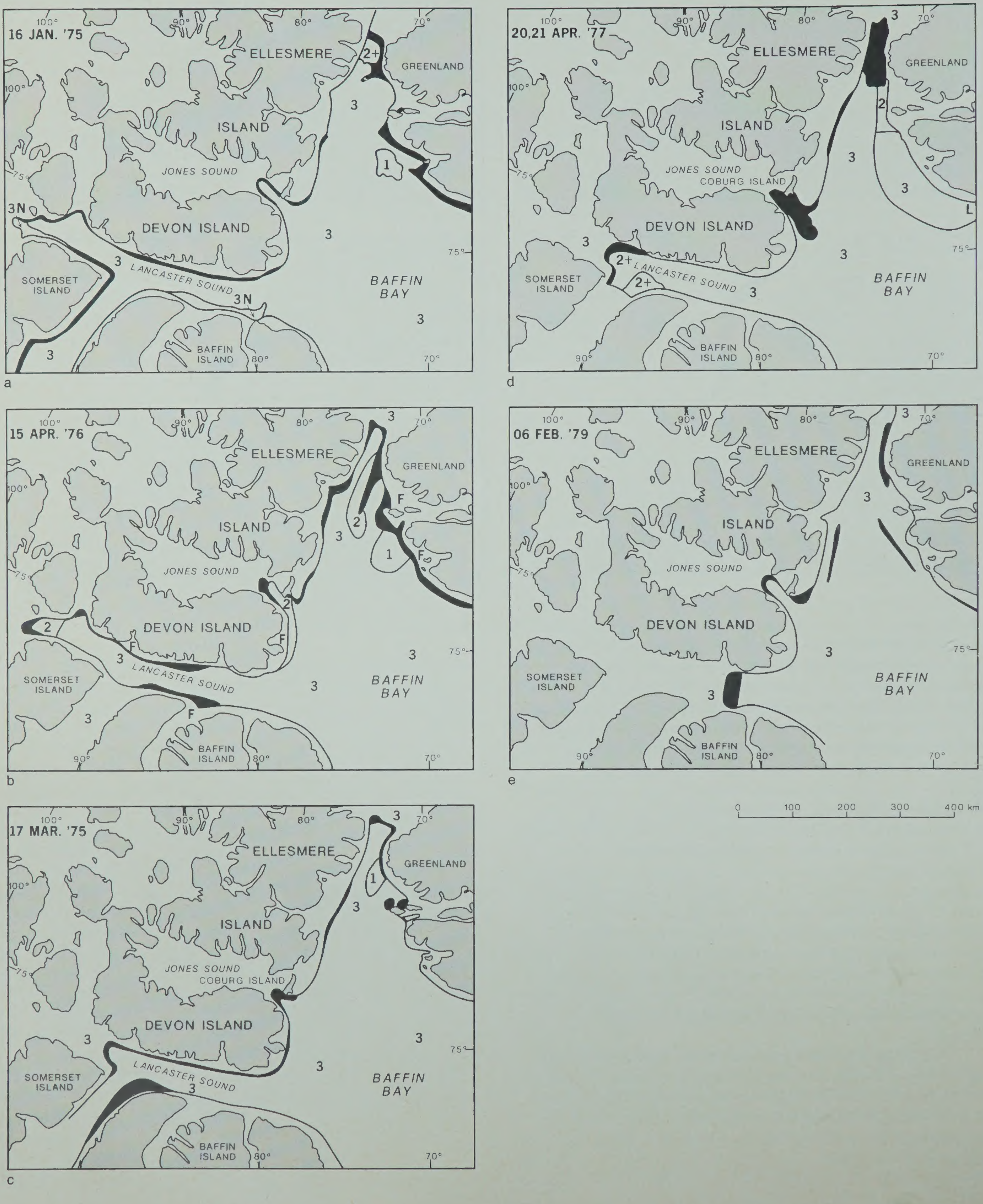
**Figures 4a–d**
Maps of the Bylot Island lead system, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



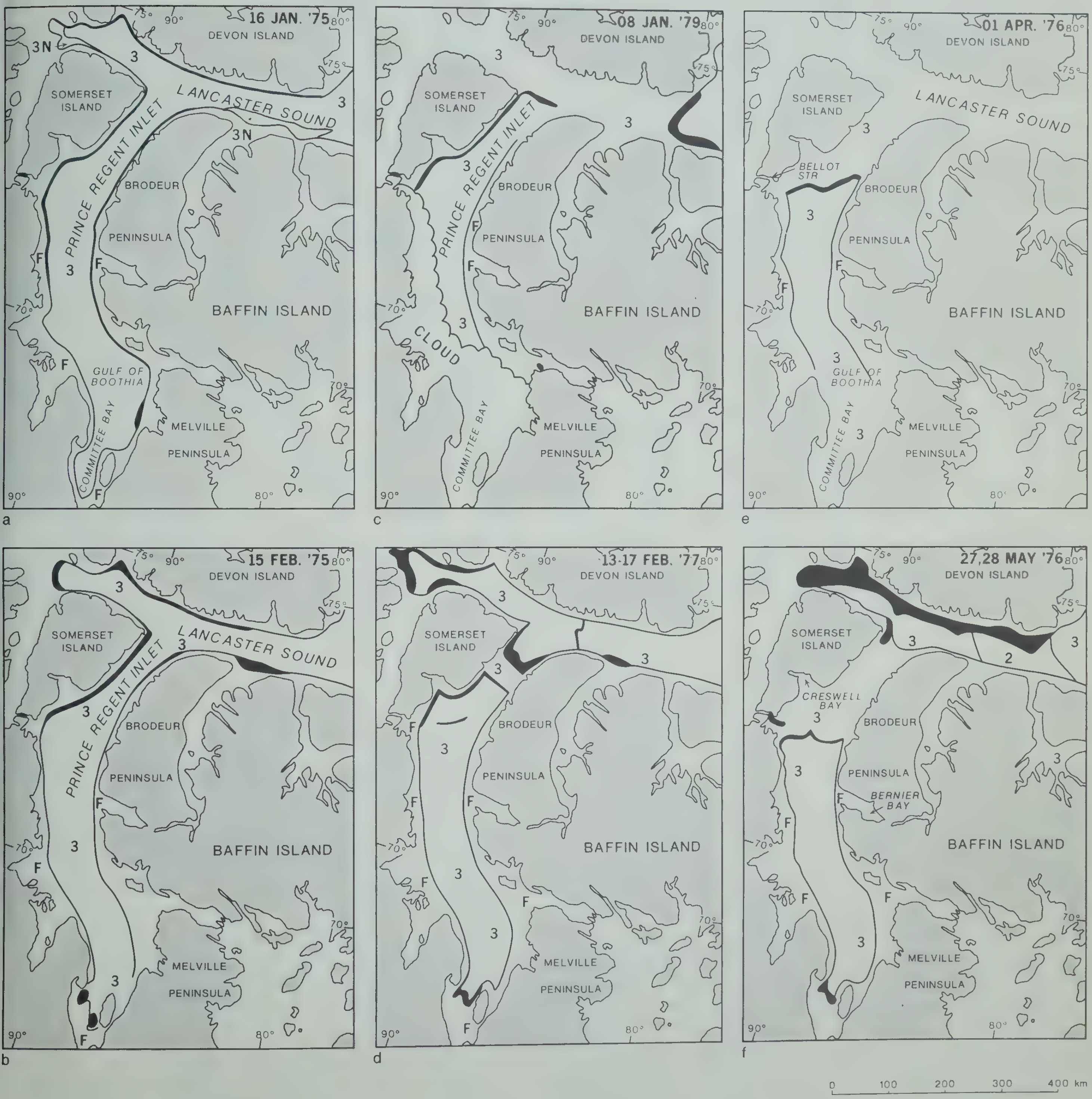
eastern coasts of Somerset Island in January and February (e.g. Fig. 6*a, b*), and there is sometimes open water along the Brodeur Peninsula at this time of year. A patch of open water may also occur at the entrance to Prince Regent Inlet (e.g. Fig. 6*c*), or an open lead across the inlet south of Lancaster Sound (Fig. 6*d*). In most years, there is a transverse lead that runs somewhere between Bellot Strait and Bernier Bay, Brodeur Peninsula, from March until mid to late June (Fig. 6*e, f*). This is a very constant feature from year to year, and only disappears with the progression of break-up. (The only exception to this pattern during the study period was in 1979, when the lead did not appear until mid June.) The location of this transverse lead may be related to the submarine topography of Prince Regent Inlet, since there is a sill across the sound in this vicinity. This sill may also influence the development of counter-clockwise currents in Prince Regent Inlet (Fig. 2). Finally, the large open lead that occurred in Creswell Bay in January and/or February in 4 of the past 5 years (Fig. 6*d*) should be noted. This lead tends to disappear with the development of the transverse lead in March.

Prince Regent Inlet was open from Lancaster Sound as far south as Bernier Bay before the end of August in 1975, 1976, and 1977. In 1979, it opened only as far south as Creswell Bay, and in 1978 only the bays and a passage along the eastern side of the inlet were open. Elsewhere, there was 8/10 to 10/10 ice cover.

**Figures 5a–e**
Maps of the Lancaster Sound lead system, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



**Figures 6a–f**
Maps of the Prince Regent Inlet lead system, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



### 5.6. Bellot Strait

The polynya in Bellot Strait can probably be attributed to the effect of currents passing through the narrow channel between Somerset Island and Boothia Peninsula (see Fig. 2). The Canadian Hydrographic Service (1970) mentions the existence of strong currents on the eastern side of the strait, which may explain the regular extension of the polynyas into that area.

Between the end of September and December, Bellot Strait and the areas off each end of the strait, in Prince Regent Inlet and Franklin Strait, become ice-covered (Fig. 7*a, b*). Open water occurred in the middle of Bellot Strait between late December and March in all 5 years (e.g. Fig. 7*c*). It first appeared in December in 1975 and 1978, and in January in 1976, 1977, and 1979. In April and May the polynya moves to the eastern end of the strait and enlarges, extending into Brentford Bay (Fig. 7*d*). Break-up usually occurs in June, but conditions are highly variable from year to year, depending on break-up patterns in Prince Regent Inlet and Franklin Strait. During this period Bellot Strait can be completely frozen over (1976), open in the middle with ice at either end (1977, 1978, 1979), or totally open into Brentford Bay (1975).

From late June until the end of September, Bellot Strait remains open and connects to open water in Prince Regent Inlet (Fig. 7*e*). In 3 years (1975, 1976, 1977), there was open water off both ends of the strait by late August/early September (Fig. 7*f*). In 1978 and 1979, open water was present only at the eastern end of the strait.

### 5.7. Committee Bay

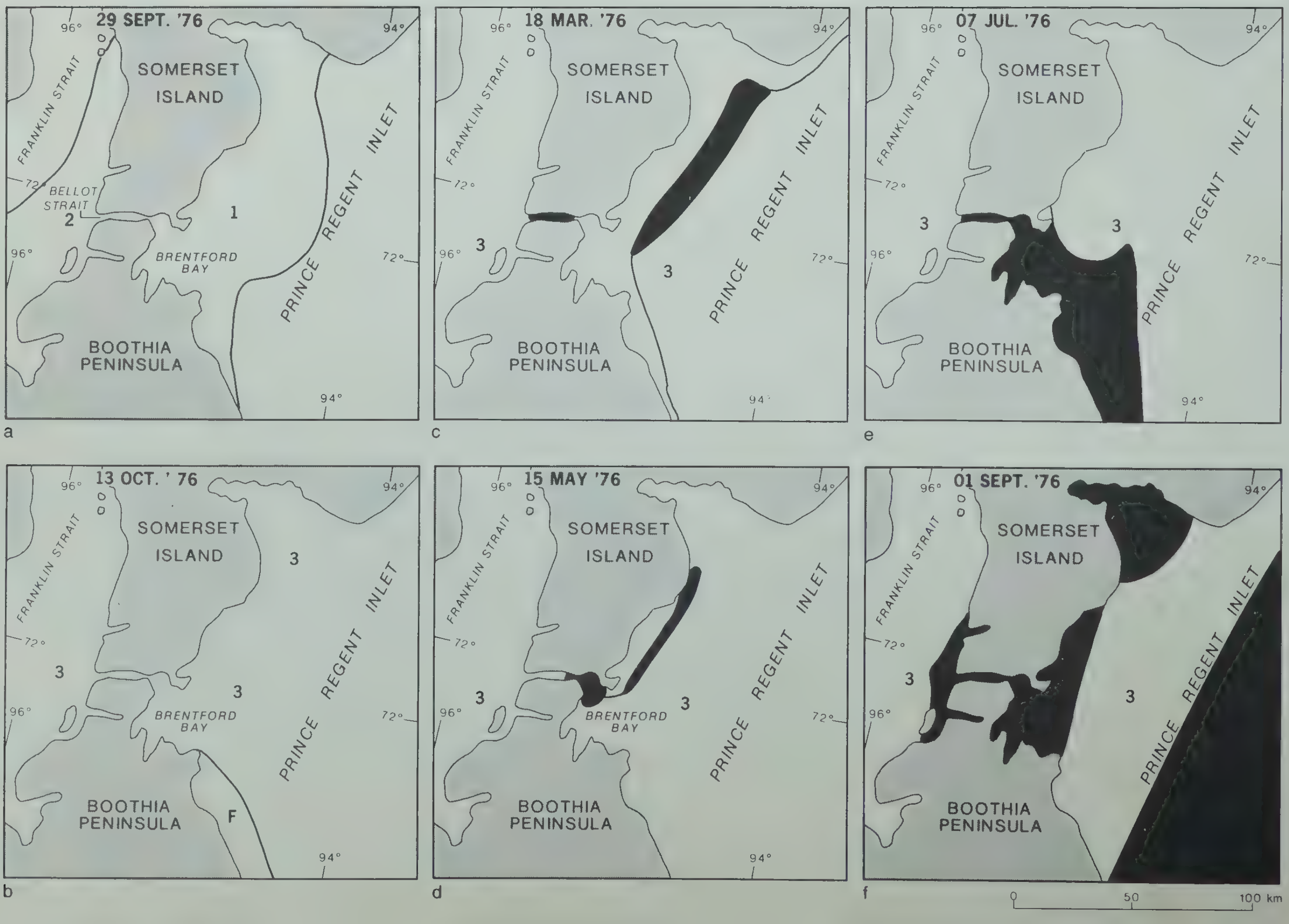
A polynya was present in Committee Bay, between Wales Island and Simpson Peninsula, in all 5 years, first appearing in either January (1977), February (1975, 1976, 1979), or April (1978). Although it initially varied in size, shape, and specific location between years, it usually adopted a fairly characteristic form by April (Figs. 6*a–f* and 8*a*).

Freeze-up in this area begins either in early September (1976, 1977, 1979), mid September (1977), or early October (1975). Landfast ice forms along the shore while the middle of the bay is filled with predominantly second and multiyear ice, which drifts in from the Gulf of Boothia.

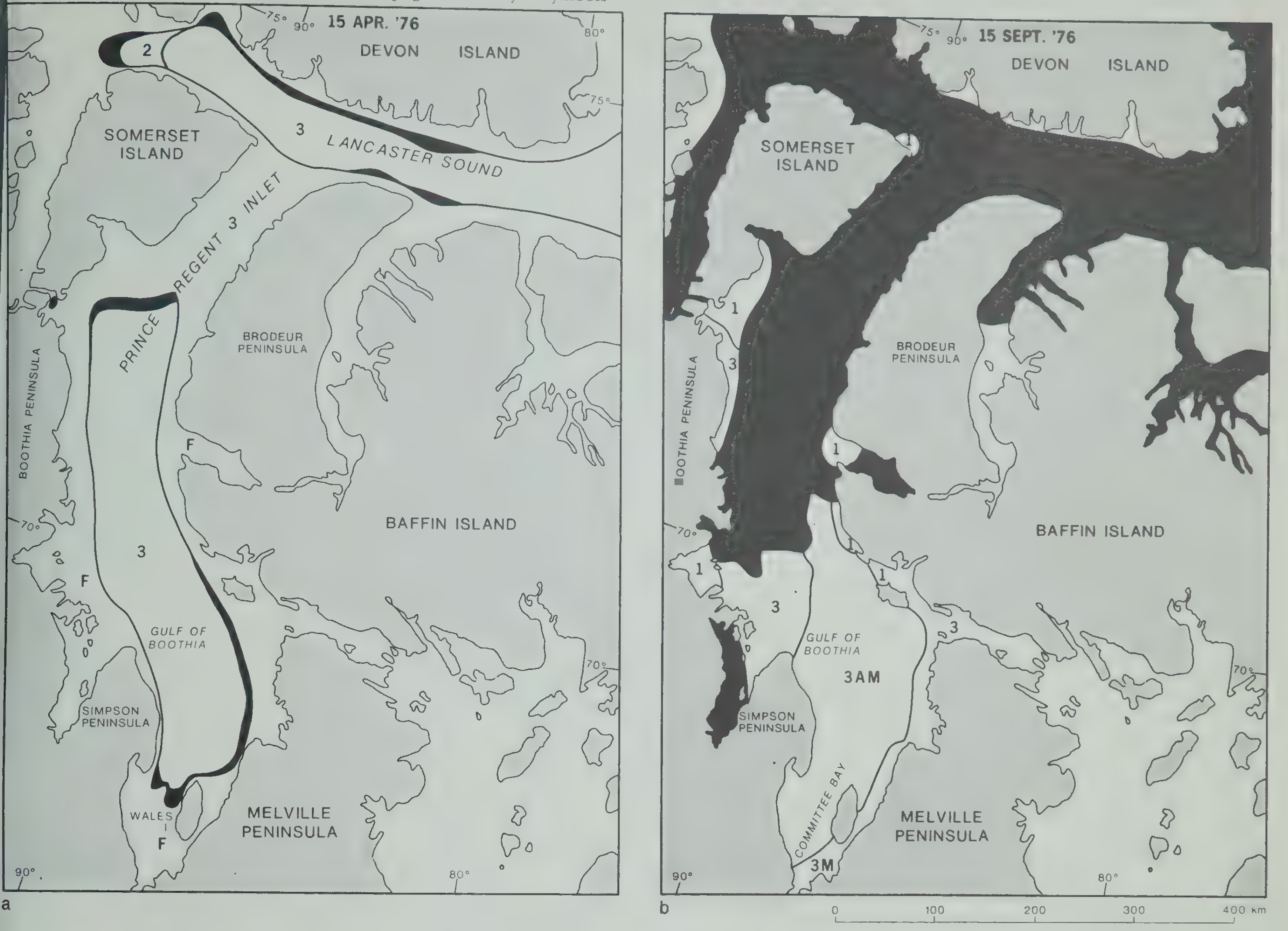
The polynya seems to be part of a shorelead system that develops between the shorefast and pack ice in Prince Regent Inlet, the Gulf of Boothia, and Committee Bay (Fig. 6*a*). It is difficult to explain why this polynya occurs since bathymetric and current information are lacking. Nevertheless, we think that wind and tidal action may be important. The maximum tidal range at Fort Ross, Bellot Strait, is 2.5–3 m, and it is likely to be greater to the south in Committee Bay.

After formation, this polynya persists until early June, at which time the ice in the Gulf of Boothia and Committee Bay becomes more mobile and the landfast ice starts to break up. At maximum break-up there is open water along the coast but Committee Bay itself is never ice free (Fig. 8*b*). In September 1975 however, an exceptionally large portion of the bay was open to Prince Regent Inlet.

**Figures 7a–f**
Maps of the Bellot Strait polynya, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



**Figures 8a and b**
Maps of the Committee Bay polynya, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



## 5.8. Foxe Basin

Freeze-up usually begins in the northwestern corner of Foxe Basin in mid October and extends south to Southampton Island by early to mid November. In 1978, freeze-up occurred a few weeks earlier. The ice cover in Foxe Basin is characterized by annual ice, with fast-ice zones around the islands and along the shoreline. As a result of winds, tides, and currents, the main pack remains continually in motion. A large proportion of Foxe Basin almost always shows up as quite dark on the NOAA imagery, perhaps because the constant movement keeps it from getting too thick.

Normally, by the beginning of January a characteristic pattern of cracks, leads, and patches of open water develops in northern Foxe Basin, varying little from year to year (e.g. Fig. 9*a*). Open water appeared as soon as early December in 1975 and 1978, north and northeast of Prince Charles Island and from the southern end of Fury and Hecla Strait south past Igloolik Island in 1975, and between Igloolik Island and Jens Munk Island and north of Rowley Island in 1978.

By mid February or, more often, early March, one typically finds open shoreleads around Koch Island, Rowley Island, Baird Peninsula, Foley Island, and the Spicer Islands. An open lead also develops between the fast ice and the pack ice on the southeast side of Prince Charles Island and on the southern side of Air Force Island. In some years, the open water extends south along Taverner Bay, Baffin Island (Fig. 9*b*). The polynya off Rowley Island linked up with the Spicer Islands polynya in mid April 1978 (e.g. Fig. 9*c*), and in mid to late May in 1976, 1977, and 1979.

Usually by the beginning of January there is an open lead between Jens Munk Island and Igloolik Island (Fig. 9*a*). This polynya, which has a characteristic horseshoe shape, remains throughout the winter. There is also another open lead which develops sometime in February (1977, 1979) or March (1975, 1978) from Cape Wilson south past Winter Island (Fig. 9*b*). This lead also persists until break-up. In 1976, there was only a small patch of open water, which appeared off Cape Wilson in May.[1]

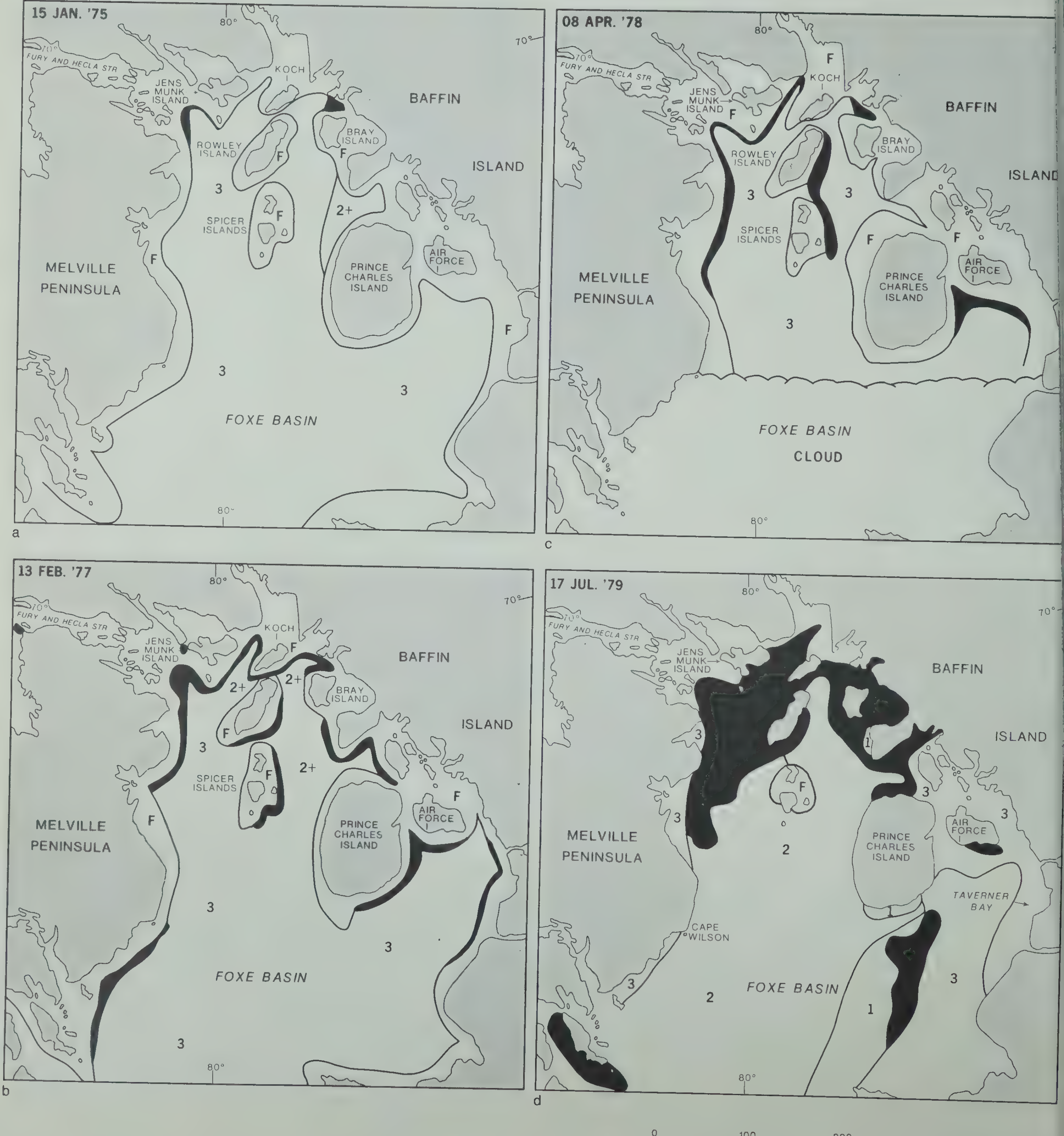
The polynyas off Rowley Island, Spicer Islands, Prince Charles Island, Air Force Island, and Cape Wilson are all to the south or southeast. Presumably, this is largely a result of winds predominantly from the northwest (Markham 1962); a similar effect has been noted previously in Ungava Bay and Hudson Bay (Stirling *et al.* 1977).

By mid May in all years, a large area of open water develops in northwestern Foxe Basin, between Hall Point, Jens Munk Island, and Rowley Island. This open water grad-

---

[1] The lead system off northern Southampton Island was not mapped consistently because it was peripheral to the main study area.

**Figures 9a–d**
Maps of the Foxe Basin polynyas, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



ally enlarges towards the southeast, and the other areas of pen water described above gradually begin to coalesce Fig. 9*d*). Open water frequently extends along the lead off ape Wilson. The early opening of northwestern Foxe Basin as been related to prevailing northwesterly winds and outhward-flowing currents (Markham 1962).

As break-up progresses, a complex and variable pattern of open water and loose ice develops, depending on wind conditions and the pattern of break-up itself. A general clearing of ice in Foxe Basin, through Hudson Strait, usually occurs by late August to late September, although it did not clear in 1978. Fury and Hecla Strait does not often clear in the summer, because it tends to be blocked with ice flowing out of the Gulf of Boothia.

### 5.9. Hell Gate – Cardigan Strait

Hell Gate and Cardigan Strait are narrow passages between North Kent, Devon, and Ellesmere islands, through which strong currents flow from Norwegian Bay to Jones Sound (Fig. 2). A well-known recurring polynya occurs there because of these currents. From the past 5 years of data it is possible to delimit a core area to the polynya which appears in a fairly constant pattern from year to year.

Freeze-up normally occurs in this area sometime in September; the bays and fjords freeze first with new ice. Elsewhere the ice is usually a mixture of grey, grey-white, and new; in some years there is 1st-year ice also, and occasionally some multiyear ice. The older ice comes from Norwegian Bay and gets clogged in the strait. Throughout October and November, Hell Gate and Cardigan Strait are covered with 9+/10 ice, although the ice appears to remain mobile within the area. In November 1978, there was only 6/10 to 8/10 ice cover, since Norwegian Bay did not break up that year and there was less clogging of the strait.

Open water usually reappears in early December, on either side of North Kent Island, frequently occurring first on the eastern side of the island. From December until July, open water remains, with the maximum extent occurring in May, June, and July. Conditions and concentrations of ice may be quite variable throughout the winter and between years (Fig. 10*a–f*). Nevertheless, the polynya often remains ice-free along the southeastern edge, possibly because of the submarine shelf that runs across Jones Sound between Cape Storm on Ellesmere Island and Cape Svarten on Devon Island. During the period of maximum extent (May–July) the core area is ice-free and isolated from Jones Sound.

In July, break-up normally occurs in Norwegian Bay, and ice flowing south from here tends to block Hell Gate and Cardigan Strait. Because of this, the area does not usually become completely ice-free in summer. In most years, Jones Sound is open during August, while there may still be 6/10–8/10 ice cover in Hell Gate and Cardigan Strait. When freeze-up occurs in September, the ice cover consists of a mixture of new ice, 1-year-old ice, and multiyear ice.

### 5.10. Queens Channel and Penny Strait

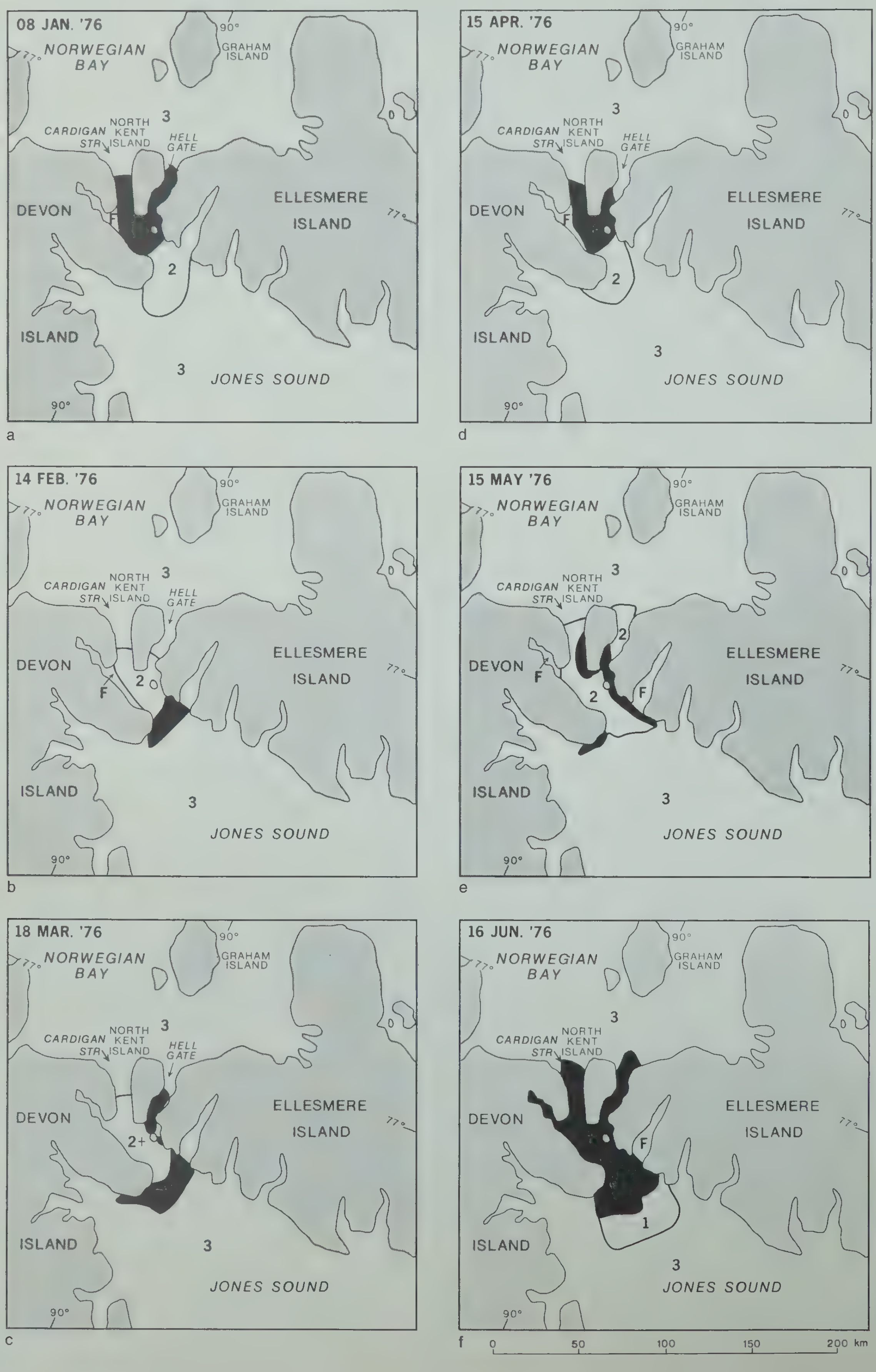
A well-known polynya system occurs in the vicinity of Dundas Island (see frontispiece) and Penny Strait, probably because of the strong currents and predominantly shallow water that prevail throughout the area. Freeze-up usually occurs in this region in late September or early October, with the exception of 1976 when it took place in mid October. Freeze-up occurs first in Penny Strait and the area to the northwest of Cornwallis Island in Queens Channel and McDougall Sound. Wellington Channel and the area around Dundas and Baillie-Hamilton islands may have anywhere from 2/10 to 8/10 ice at this time. Within 2 weeks these latter areas freeze up as well, at which time there is a characteristic alignment of ice (Fig. 11*a*). Although the ice throughout this region is usually composed of annual ice, in 1978 and 1979 northern Wellington Channel did not become free of ice during the summer. Therefore the connection to Lancaster Sound did not occur any further north than approximately Griffin Inlet on Devon Island.

In January (December in 1978), an area of open water appears in Couch Passage between Dundas Island and Baillie-Hamilton Island, or in Pioneer Channel between Dundas Island and Sheills Peninsula on Devon Island (Fig. 11*b*). This feature persists through the winter months (Fig. 11*c*, *d*). At its maximum extent, which usually occurs around the end of April or in early May, the waters between these land masses remain completely open (Fig. 11*e*). With the beginning of break-up, usually in June, Couch Passage and Pioneer Channel tend to clog with ice flowing from Penny Strait, presumably because of the southerly flowing currents in this region (Fig. 2). The shallow depth of the channels and the positions of the islands combine to act as a bottleneck. The jammed ice disappeared in early to mid July in 1976 and 1977, and around the end of July in 1975 and 1978. In 1979, because of the ice conditions, it was not possible to tell when or even if the ice jam disappeared.

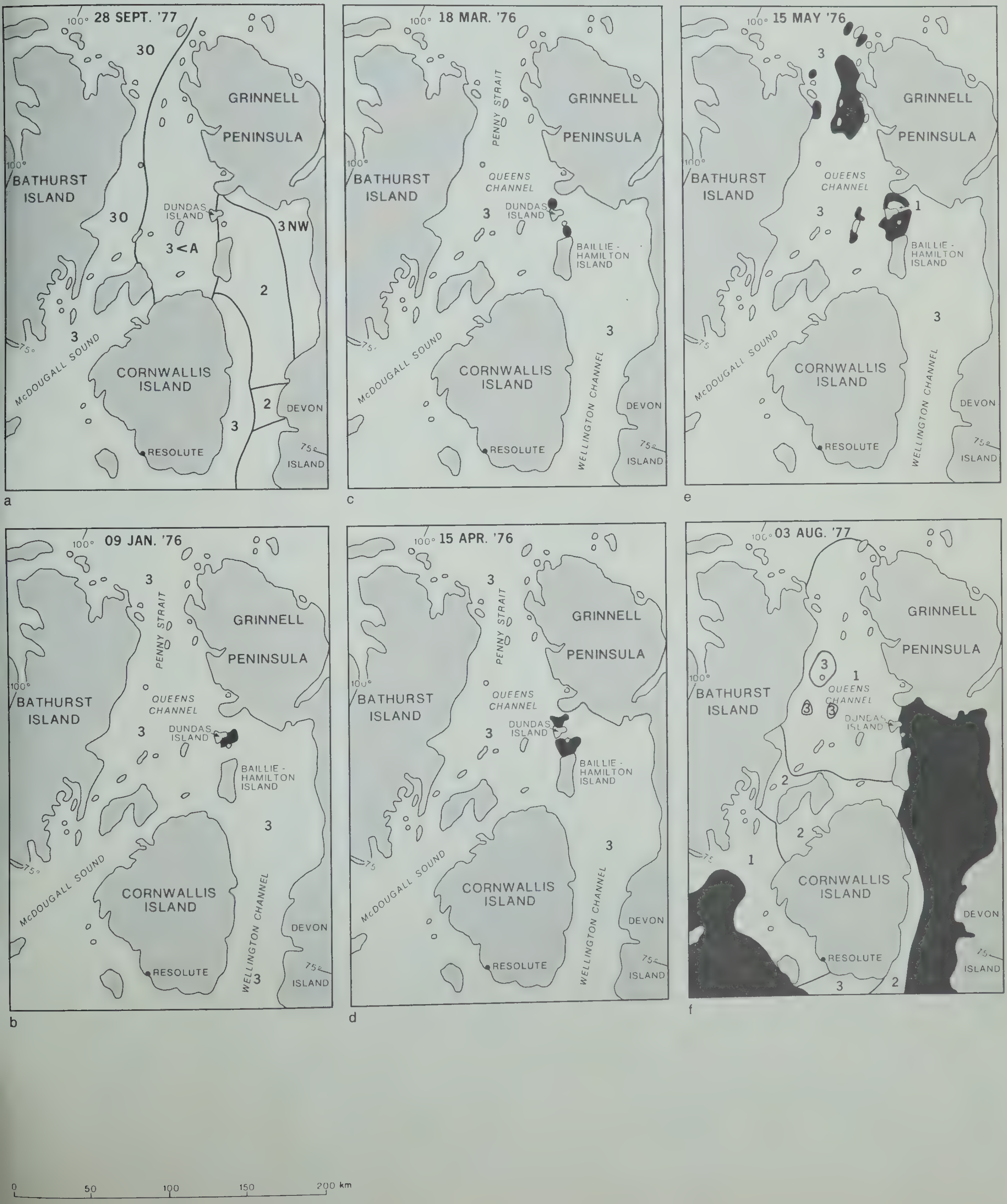
Several small polynyas develop in May or early June along the eastern side of Penny Strait (Fig. 11*e*). Although these polynyas may not open particularly early, they precede break-up and seem to occupy a constant location from year to year. As break-up proceeds through June, the separate patches of open water coalesce until the whole strait is clear of ice (usually by mid June). Finally, by late June to mid July, the open waters of Penny Strait link up with the open water around Dundas Island, although in 1978 the two areas did not unite until the beginning of August. The area around Dundas and Baillie-Hamilton islands joins the open water in Wellington Channel (and hence Lancaster Sound) sometime between mid July to mid August (Fig. 11*f*). In 1978 and 1979, these areas did not join because Wellington Channel remained full of ice as far south as approximately Griffin Inlet.

Southerly flowing currents carry ice from Queens Channel and Penny Strait south through Wellington Channel to Lancaster Sound. McDougall Sound, between Bathurst and Cornwallis islands, was never observed to be completely free of ice in any of the 5 years.

**Figures 10a–f**
Maps of the Hell Gate – Cardigan Strait polynya, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



**Figures 11a–f**
Maps of the Queens Channel – Penny Strait polynyas, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



### 5.11. Arctic Ocean lead system

The Arctic Ocean is covered with pack ice which, under the forces of currents and winds, gradually moves in a clockwise direction. A zone of landfast ice forms along the outer Queen Elizabeth Islands, western Banks Island, and along the mainland coast (Fig. 12). Freeze-up along Banks Island can begin between the first of October (as in 1978) and the first of November (as in 1977), or a week or two later along the mainland coast.

The boundary between the fast ice and the pack ice is commonly marked by a shorelead system which remains relatively constant from year to year, and corresponds to the continental shelf (Fig. 12). The lead system is often continuous from north of Ellef Ringnes Island south to Cape Bathurst on the mainland, and then west past Point Barrow, Alaska. In January 1975 it extended as far north as Robeson Channel, between Ellesmere Island and Greenland.

The lead opens and closes as the pack ice moves; thus it varies in width and continuity. It takes the form of some combination of leads, cracks, and patches of open water (Fig. 12) which in places may stretch up to tens of kilometres wide during winter. For short periods, open water may exist in the lead but, because of the rapid rate of ice formation in winter, there is usually a cover of new ice (Weeks 1978). As stated previously, it was not possible to differentiate new ice from open water on the NOAA imagery, so that all dark areas were mapped as open water. As the lead closes, the new ice is rafted or forced into pressure ridges which can be seen clearly even on NOAA images. From the daily coverage provided by the NOAA imagery, it appears that the pack ice moves in and out quite frequently so that open water and/or new ice are persistent along this shorelead system.

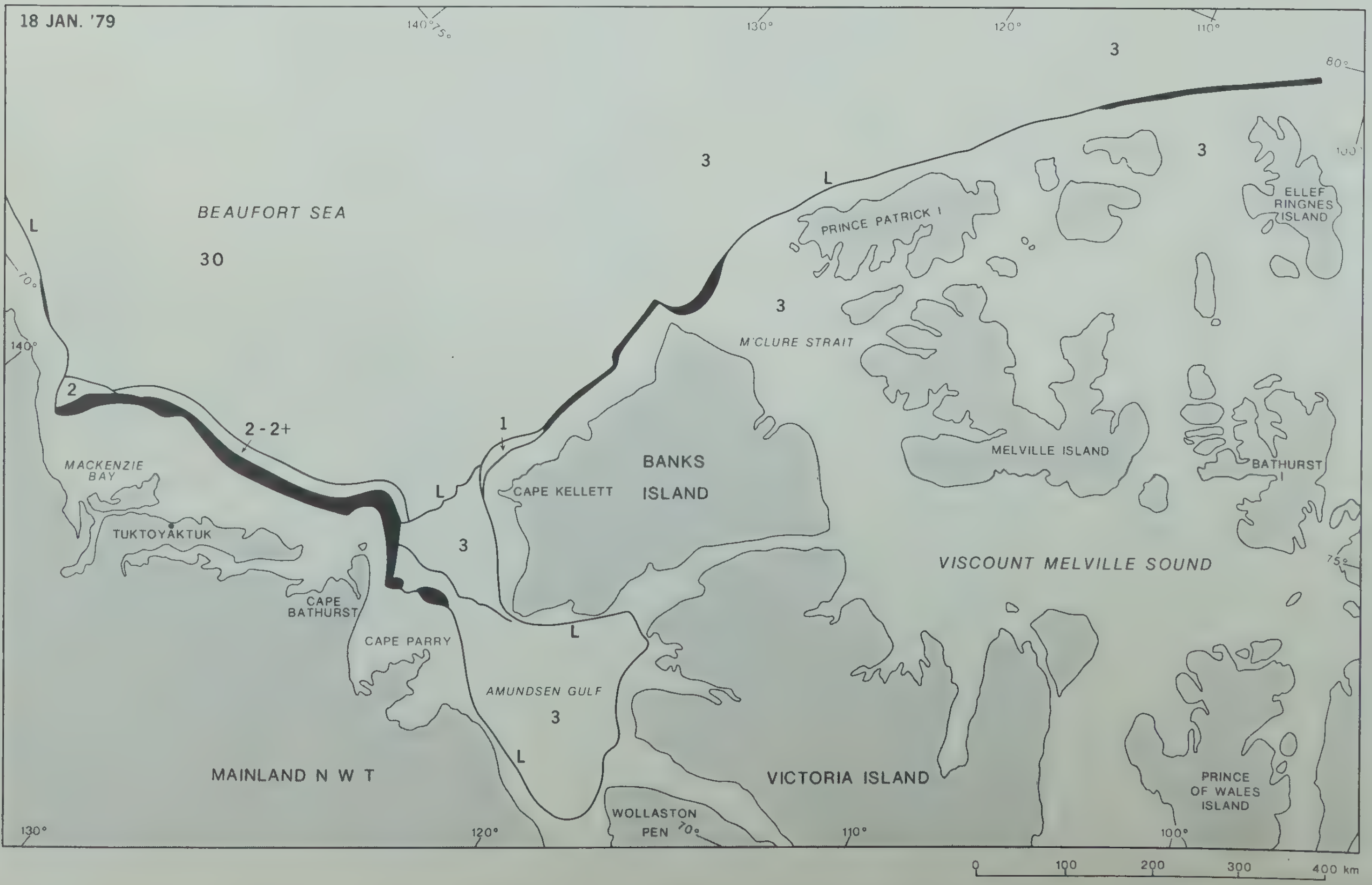
For ease of discussion, we have divided the Arctic Ocean lead system into the following regions: (1) Prince Patrick Island/M'Clure Strait/Banks Island, (2) Cape Bathurst/Amundsen Gulf, and (3) Cape Bathurst to Point Barrow, Alaska.

### 5.11.1. *Prince Patrick Island*

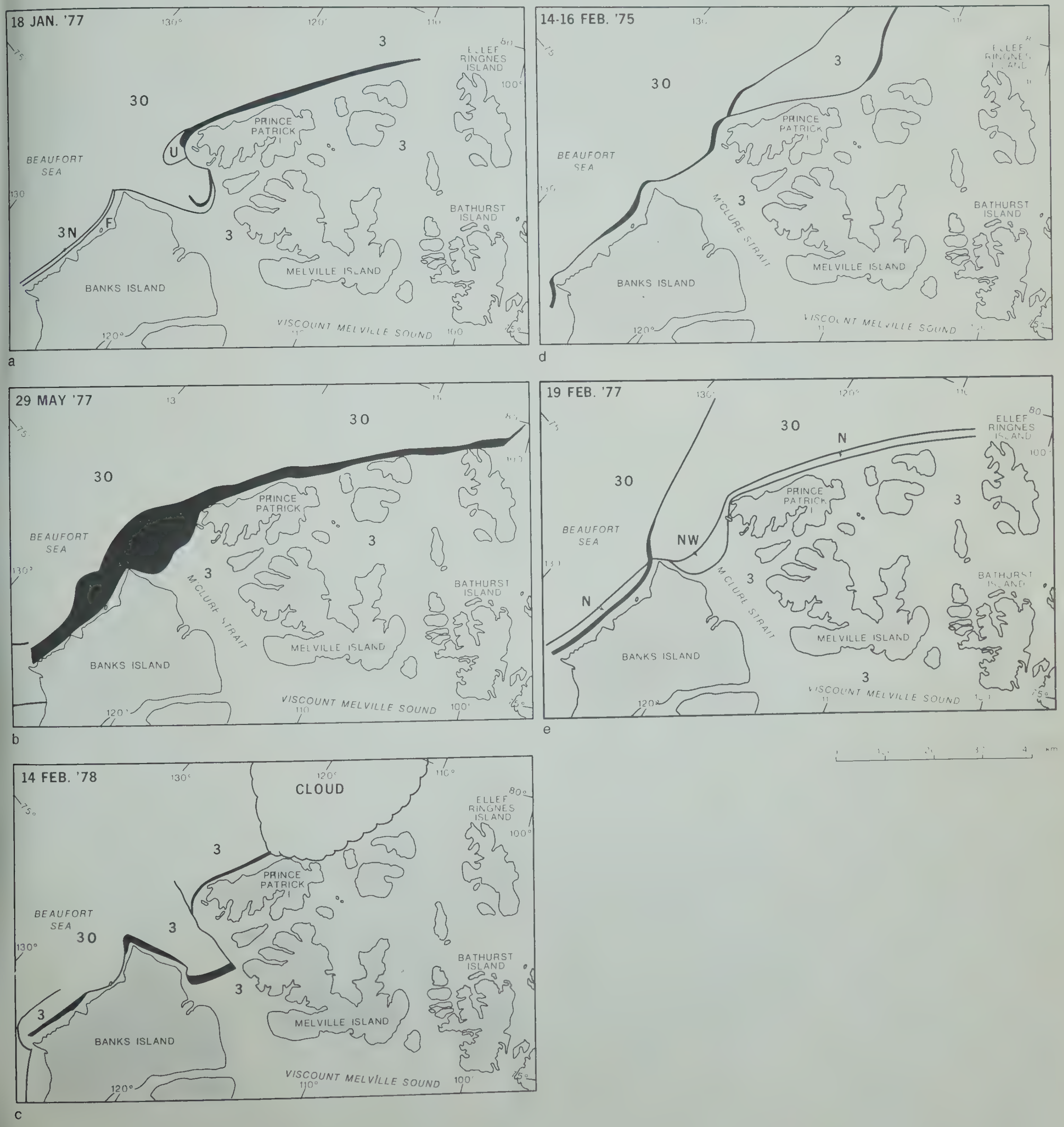
The northwestern coast of Prince Patrick Island (and northwards to Borden and Ellef Ringnes islands) usually remains ice-bound throughout the year. Open water occurred along the Arctic Ocean shorelead as early as mid November in 1975 and 1976, while in other years it occurred sometime in January (e.g. Fig. 13*a*). In 1975, open water remained until early July (although none was present in March, April, and the first half of May). In 1976, it persisted right through until early June, while in 1977 there was open water until early July (except in April). In 1978 there was some open water in February but, because of the combination of heavy cloud and poor or missing images, we have no further data until early June, when there was no open water. In 1979, there was open water until mid June (but no data for February and March because of bad weather).

The maximum extent of open water occurs sometime in the period from April to July, frequently in May (e.g. Fig. 13*b*). At this time, open water is usually continuous from Cape Bathurst to north of Ellef Ringnes Island. By July, with increased mobility of the pack ice, the lead tends to close off and ceases to be a continuous feature. In some years, however, isolated open water can occur after this date: in early July and mid August of 1978, there was open (or semi-open) water between Borden and Ellef Ringnes islands and from

**Figure 12**
Map of the Arctic Ocean lead system, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



**Figures 13a–e**
Maps of the Prince Patrick Island lead system, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



late August to mid September 1978 and in late August 1979 there were various openings offshore between Borden and Prince Patrick islands.

Associated with the Prince Patrick system is an area of open water at the entrance to M'Clure Strait. This is perhaps a shear zone between the Arctic pack ice and the fast ice in the strait. Open water can appear there as early as January (1977, Fig. 13*a*) or February (1975, Fig. 13*d*), and there is usually open water by mid May in most years. In 1978, however, the lead was closed between April and July. Earlier in the year during February, open water occurred in M'Clure Strait near Mercy Bay on Banks Island (Fig. 13*c*); however, the normal position is like that shown in Figure 13*d* and *e*. Open water is generally not present in M'Clure Strait after the beginning of July (although it was in 1977).

Also related to the Prince Patrick system is an opening extending south along the western side of Banks Island. Open water first appeared here at various times ranging from early January in 1977 to late February in 1975 and 1978. Like the Prince Patrick lead, the presence of open water is determined by movements of the pack ice, and it attains its maximum extent between May and July (Fig. 13*b*). In late summer the pack recedes northwestwards, usually leaving the west coast of Banks Island open by early September. Landfast ice starts to form in the north, and the pack moves back toward the shore sometime between mid October and early November (1976, 1977, 1979). In 1975, this occurred in late August/early September, and in 1978 it did not open up in summer to the same extent as it had in other years.

### 5.11.2. *Cape Bathurst*

Some open water can be found in virtually all months somewhere in western Amundsen Gulf in the area of Cape Bathurst, Cape Parry, and Cape Kellet (Banks Island). Open water can appear as early as sometime in December, although it is not until April that a characteristic form to the polynya appears. Open water appears along the fast-ice boundary, although the current flowing eastwards into Amundsen Gulf may play a role.

Freeze-up occurs in this region sometime between mid October (1975, 1978), early November (1976, 1979) and mid November (1977), and takes 2–3 weeks. The pattern of freeze-up progresses along the coast from the northwest, terminating in Amundsen Gulf. Overall, the ice cover is made up primarily of annual ice. By mid December, a characteristic pattern of cracks and leads starts to develop along the fast-ice boundary, which follows the edge of the continental shelf. This system extends right around Amundsen Gulf (Fig. 14*a*).

During each of the 5 years an open lead developed off the eastern side of Cape Bathurst sometime in January (Fig. 14*a*). This coincided with the appearance of open water just north of Cape Parry in 4 of the 5 years. Open water remains in the general area, in some form, until late May to early June when, characteristically, the area between Cape Bathurst and Cape Kellett opens up to form a disintegration area. Until April, the size, shape, and location of open water is quite variable by month and by year (e.g. Fig. 14*b*). By April in most years, however, the polynya exhibits a more or less typical form (Fig. 14*c–f*). With the advance of break-up, the open water between Cape Bathurst and Cape Kellett enlarges into Amundsen Gulf. In addition, open water develops northwards, along Banks Island, and westwards to Mackenzie Bay (see Fig. 14*g*, *h*). The extent to which the shorelead polynya system in the Beaufort Sea is open is mainly dependent upon wind since this influences the movement of the Arctic pack. The coast was open to Mackenzie Bay in all five summers, and as far west as Barter Island in three.

### 5.11.3. *West of Cape Bathurst*

A recurrent crack and lead system develops between the landfast ice and arctic pack, along the coast west from Cape Bathurst to beyond Point Barrow. According to Marko (1975), "the seaward boundary of landfast ice may usually be identified by its coincidence with a persistent lead (along the Tuktoyaktuk Peninsula) that roughly follows the 30-m depth contour and changes its position very little from year to year." Marko also identifies a transition zone between the landfast ice and pack ice, which includes open water, new ice, and mobile ice. This transition zone is visible on the NOAA imagery.

Freeze-up along the western arctic coast usually occurs first in the area between Mackenzie Bay and Point Barrow sometime between the end of September (as in 1975) and the beginning of November (as in 1977, 1979). In the Cape Bathurst – Mackenzie Bay area, freeze-up occurs roughly 2 weeks later, between mid October (as in 1975) and mid November (as in 1979). West of Point Barrow, freeze-up is usually later still, between the end of October (1975) and mid November (1976, 1979). The crack and lead system along the boundary of the landfast ice usually appears about the middle of November.

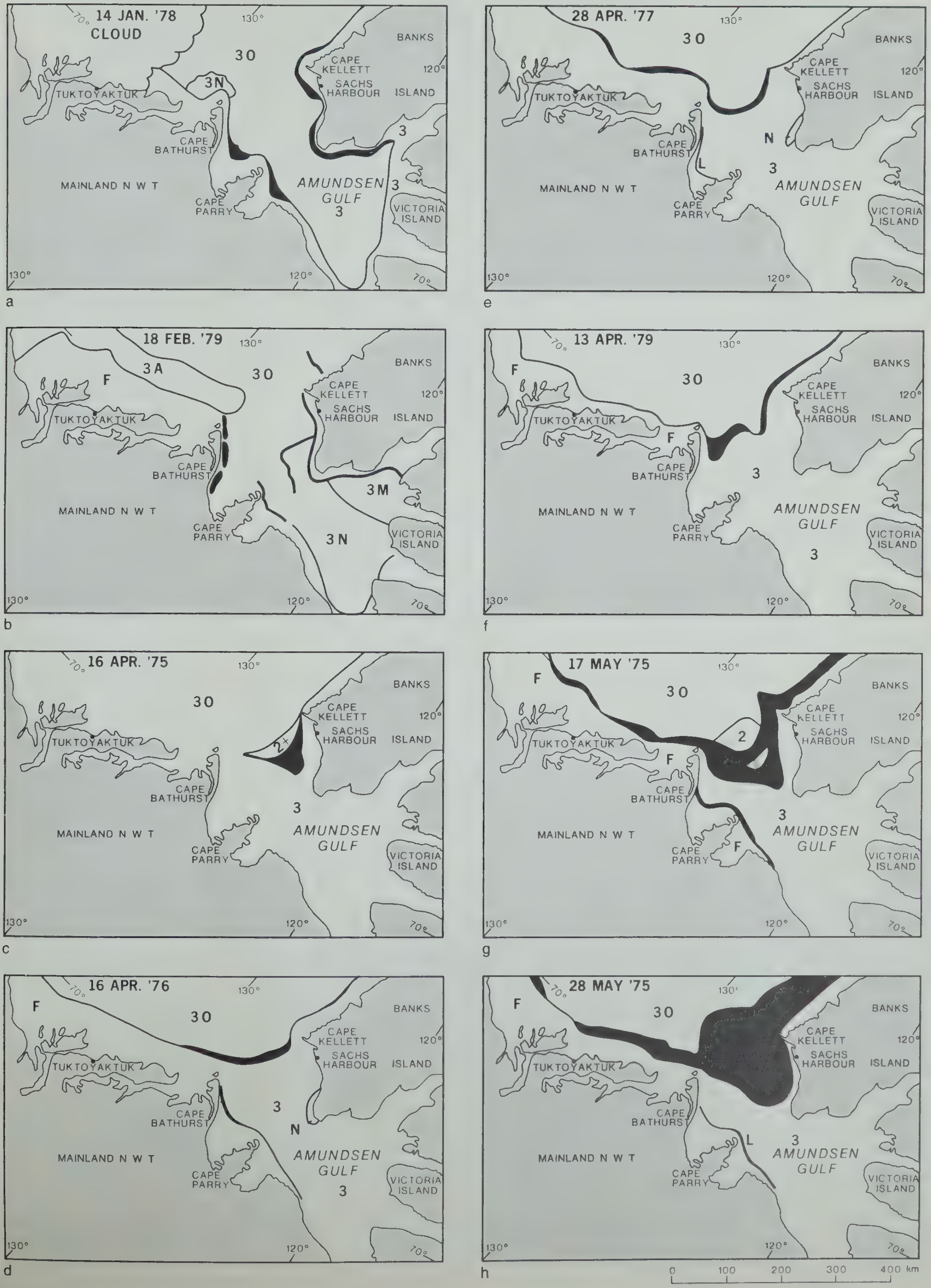
Patches of open water and new ice occur frequently during the winter between Cape Bathurst and Mackenzie Bay (Fig. 15*a*, *b*). As early as November (1976) or December (1975, 1977) open water may appear. Throughout the winter months, openings can be found within this area, but it is not usually until mid May that the open water is continuous from Cape Bathurst to Mackenzie Bay. There was a continuous opening in January 1979, and in 1978 it developed in mid February and remained throughout the winter.

In contrast to the region discussed above, sizeable areas of open water rarely occur between Mackenzie Bay and Point Barrow for any length of time during the winter. The lead along this part of the coast tends to remain closed. In the area west of Point Barrow, however, open water and new ice is evident in most months, but, again, it does not become continuous and extensive until about mid May (Fig. 15*c*).

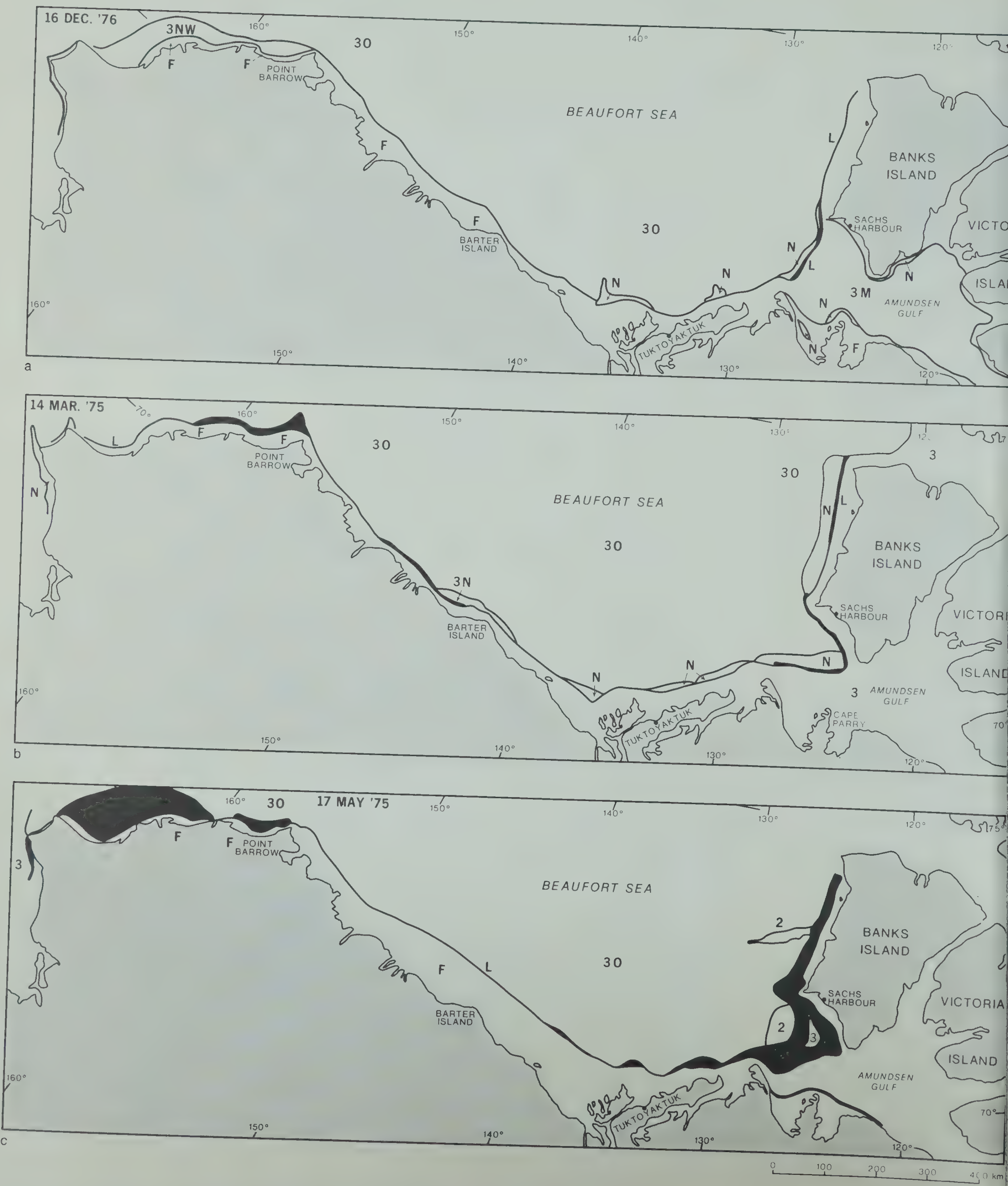
Break-up, which is characterized by progressive widening of the lead system, usually commences in mid June (except mid May in 1979). As break-up progresses, a narrow continuous lead develops along the whole coast from Cape Bathurst to Point Barrow, with the region between Mackenzie Bay and Point Barrow being the last to open. The lead first becomes continuous sometime between mid July and mid August, with the exception of 1975 when the coast remained ice-bound. By the end of September or early October, the lead enlarges to quite an expanse. Off Point Barrow, the open water at the maximum extent was from 60 km (in 1978) to 450 km wide (in 1979).

The reader is referred to the recent paper by Carleton (1980) for a description of the Cape Thompson polynya, off northwestern Alaska.

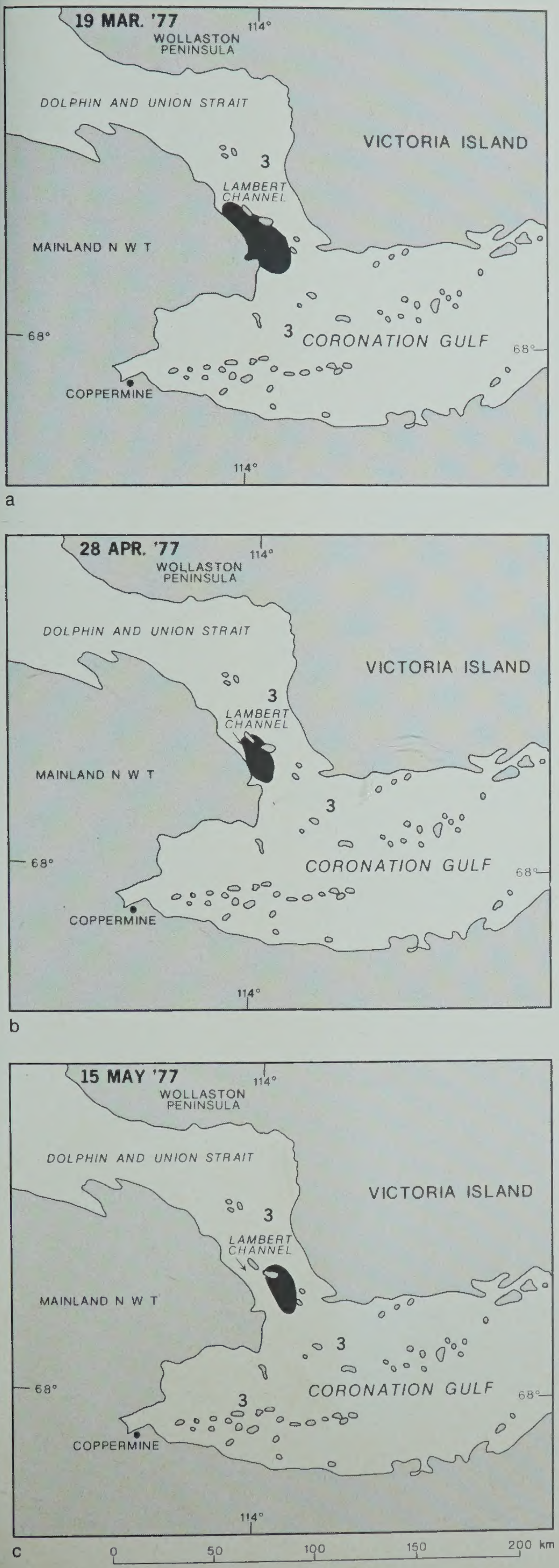
**Figures 14a–h**
Maps of the Cape Bathurst polynyas and adjoining lead systems, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



**Figures 15a–c**
Maps of the lead systems west of Cape Bathurst, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



**Figures 16a–c**
Maps of the Lambert Channel polynya, showing ice conditions during particular months and years as indicated. See Figure 3, page 10, for key to symbols



5.12. Lambert Channel

There is a small polynya in southern Dolphin and Union Strait, between Victoria Island and the mainland. Open water appeared in February in 1978, by mid March in 1977, by mid April in 1979, while in 1976 it did not occur until June. In 1975 it was difficult to determine the earliest date, because of heavy cloud cover. It was, however, open in early July, when surrounding areas were still covered with 10/10 ice. In mid May 1975, there seemed to be open water in the Duke of York Archipelago, in the centre of Coronation Gulf.

Freeze-up begins between mid October and early November in Coronation Gulf and along the mainland coast. Lambert Channel freezes before the eastern side of Dolphin and Union Strait and is usually ice-covered by the end of October or the beginning of November.

Lambert Channel is very shallow in places and contains numerous shoals. Hydrographic charts indicate it has a strong current with heavy tidal rips. Open water usually appears first on the southwestern side of Lambert and Camping islands in Lambert Channel (Fig. 16*a–c*). The polynya typically remains until break-up commences in the first part of July and connects with Amundsen Gulf in mid to late July (1976, 1977) or early August (1975, 1978, 1979).

5.13. Franklin Strait

A small polynya area recurs on the eastern side of Franklin Strait in a group of islands known as the Tasmania Islands (Stirling, this publication, Fig. 1). This polynya is not visible on NOAA imagery, but has been identified on Landsat imagery. It is irregular in shape and approximately 1½–2 km in diameter. Young unstable ice prevails in this area, apparently because of strong currents that pass through the strait. Patches of open water are present by April in some but not all years (R.E. Schweinsburg, pers. commun.).

## 6. Acknowledgements

The authors wish to acknowledge the invaluable assistance provided by Pauline Smith during the research for and preparation of this paper. We also thank D. Mudry, F. Geddes, and P. Coté of Ice Climatology and Applications Division, Atmospheric Environment Service, for organizing the access to the satellite imagery and for some assistance in the interpretation. We are grateful to Moira Dunbar for helpful discussion and to the Department of Geography, Carleton University, for technical assistance.

## 7. Literature cited

**Aber, P.; Vowinckel, E. 1972.** Evaluation of North Water spring ice cover from satellite photographs. Arctic 25:263–271.

**Canadian Hydrographic Service. 1970.** Pilot of Arctic Canada. Vol. 1. Dep. Energy, Mines and Resour. Ottawa. 247 pp.

**Carleton, A. 1980.** Polynya development in the Cape Thompson – Point Hope region, Alaska. Arct. and Alp. Res. 12:205–214.

**Dey, B.; Moore, H.; Gregory, A. 1979.** Monitoring and mapping sea ice breakup and freezeup of Arctic Canada from satellite imagery. Arct. and Alp. Res. 11:229–242.

**Dunbar, M. 1958.** Curious open water feature in the ice at the head of Cambridge Fiord. Extrait des comptes rendus et rapports, Assemblée générale de Toronto 1957 (Gentbrugge 1958) Tome 4:514–519.

**Dunbar, M. 1969.** The geographical position of the North Water. Arctic 22:438–441.

**Markham, W.E. 1962.** Summer break-up pattern in the Canadian Arctic. Can. Dep. Transp., Meteorol. Branch Circ. Ser. TEC-421, CIR-3586. 7 pp.

**Marko, J. 1975.** Satellite observations of the Beaufort sea ice cover. Unpubl. Rep. to Beaufort Sea Proj., Dep. Environ., Victoria, B.C. Techn. Rep. 34. 137 pp.

**Muench, R. 1975.** Some observations of variations in North Water surface area and in certain atmospheric parameters. Pages 391-397 *in* Climate of the Arctic. Geophys. Inst. Univ. Alaska, Fairbanks, AK.

**Müller, F.** Unpublished. Glaciological and climatological investigation of the North Water polynya in northern Baffin Bay. Rep. on North Water Act. 1 Oct. 1974 to 30 Sept. 1975. Swiss Fed. Inst. of Technol. Zurich. McGill Univ., Montreal. 149 pp.

**Müller, F.** Unpublished. Glaciological and climatological investigations of the North Water polynya in northern Baffin Bay. Rep. on North Water Act. 1 Oct. 1975 to 30 Sept. 1976. Swiss Fed. Inst. of Technol. Zurich. McGill Univ., Montreal. 128 pp.

**Nutt, D.C. 1969.** The North Water of Baffin Bay. Polar Notes (Dartmouth Coll.) 9:1–25.

**Sadler, E. 1974.** On a polynya in Makinson Inlet. Arctic 27:157–159.

**Schledermann, P. 1980.** Polynyas and prehistoric settlement patterns. Arctic 33:292–302.

**Smiley, B.D.; Milne, A.R. 1979.** LNG transport in Parry Channel: possible environmental hazards. Unpubl. Rep. to Dep. of Fisheries and the Environ. Inst. of Ocean Sci., Patricia Bay, B.C. 47 pp.

**Stirling, I. 1980.** The biological importance of polynyas in the Canadian Arctic. Arctic 33:303–315.

**Stirling, I.; Jonkel, C.; Smith, P.; Robertson, R.; Cross, D. 1977.** The ecology of the polar bear *(Ursus maritimus)* along the western coast of Hudson Bay. Can. Wildl. Serv. Occ. Pap. 33. 62 pp.

**Tooma, S. 1978.** Summer circulation patterns, northern Smith Sound. Arctic 31:85–96.

**Weeks, W.F. 1978.** Sea ice conditions in the Arctic. Pages 1–20 *in* Arctic Sea Ice, Part 1, Rep. GD–2, World Data Cent. A for Glaciol., Boulder, CO.

Date Due

| | | | |
|---|---|---|---|
| DEC 14 '84 | | | |
| JAN 31 [illegible] | | | |
| RETURN JAN [illegible] | | | |

Pam:
551.326.2:(*41N)
SMI

46539

SMITH, Michael and RIGBY, Bruce
AUTHOR
Distribution of polynyas in the
TITLE
Canadian Arctic.

| DATE LOANED | BORROWER'S NAME | DATE DUE |
|---|---|---|
| July 20/82 | ILL - World Data Center | Aug. 23 |
| | Leah Kongrud | DEC 14 '84 |
| | Laura Gretcinger | JAN 31 [illegible] |

46539

BOREAL INSTITUTE FOR NORTHERN STUDIES, LIBRARY
THE UNIVERSITY OF ALBERTA
EDMONTON, ALBERTA T6G 2E9
CANADA

University of Alberta Library
0 1620 0332 6285